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Low Energy Stage Study

VOLUME I

EXECUTIVE SUMMARY

FOR NASA
MARSHALL SPACE FLIGHT CENTER

VOUGHT CORPORATION
an LTV company

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LOW ENERGY STAGE STUDY

VOLUME I

EXECUTIVE SUMMARY

FOR NASA
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CONTRACT NAS8-32710
DPD 553 MA-04

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FOREWORD

This Low Energy Stage Study was performed by Vought Corporation under NASA Contract NAS8-32710 for Marshall Space Flight Center from September 1977 through August 1978. The prime objective of the study was to determine the most cost effective approaches for placing automated payloads into low energy Earth orbits. These payloads are injected into circular or elliptical orbits of different inclinations with energy requirements in the range of capability between that of the Space Shuttle standard orbit altitude (296 km) and of the Shuttle with a Spinning Solid Upper Stage (SSUS-D). The study results are documented in five volumes:

Volume I	:	Executive Summary
Volume II	:	Requirements and Candidate Propulsion Modes
Volume III	:	Conceptual Design, Interface Analyser, Flight and Ground Operations
Volume IV	:	Cost Benefit Analysis and Recommendations
Volume V	:	Program Study Cost Elements and Appendices

Inquires regarding the study should be addressed to the following:

- Claude C. (Pete) Priest
  NASA-Marshall Space Flight Center
  Attention: PS04
  Huntsville, Alabama 35812
  Telephone: (205) 453-2791

- A. I. Sibila
  Vought Corporation
  P.O. Box 225907
  Dallas, Texas 75265
  Telephone: (214) 266-4451

TABLE OF CONTENTS

1.0 INTRODUCTION AND SUMMARY

The overall objective of this study was to determine the most cost effective approach for placing automated payloads into low energy earth orbit. There are many payloads destined for circular and elliptical orbits with energy requirements significantly lower than that provided by the smallest currently-planned Shuttle upper stage, SSUS-D. In addition the Shuttle user charge policy places emphasis on short length and light weight installations. The transfer of a payload from the Shuttle to a destination orbit of higher altitude and/or a different inclination involves propulsion, attitude control, payload separation, and airborne support equipment (ASE). Two impulses are required: one at perigee and one at apogee and in opposite directions. This study examines the most economic method of launching such low-energy payloads from the Shuttle. The payload delivery requirements were based on a mission model provided by NASA and incorporated payloads of the Space Transportation System 487 model applicable to the low energy regime. The model also included Scout class and some DoD payloads. The model was comprised of 129 payloads launched over the time period of 1980 through 1991.

The cost to launch all payloads of the model were derived using both NASA existing/planned launch approaches as well as new propulsion concepts. The existing/planned approaches encompassed the Shuttle integral OMS, OMS kits, recoverable Teleoperator Retrieval System, MMS PM-II propulsion module (expendable), SSUS-D, SSUS-A, and Scout. New propulsion approaches, including associated airborne and ground support equipment, were designed to meet the low-energy regime requirements. Candidate new propulsion approaches considered were solid (tandem, cluster, and controlled), solid/liquid combinations and all-liquid stages.

The study results showed that the most economical way to deliver the 129 low energy payloads is basically with a new modular, short liquid bipropellant stage system for the large majority of the payloads. For the remainder of the payloads use the Shuttle with integral OMS and the Scout from WTR for a few specialized payloads until the Shuttle becomes operational at WTR.

2.0 STUDY APPROACH

The approach used in conducting the study is outlined in Figure 1.

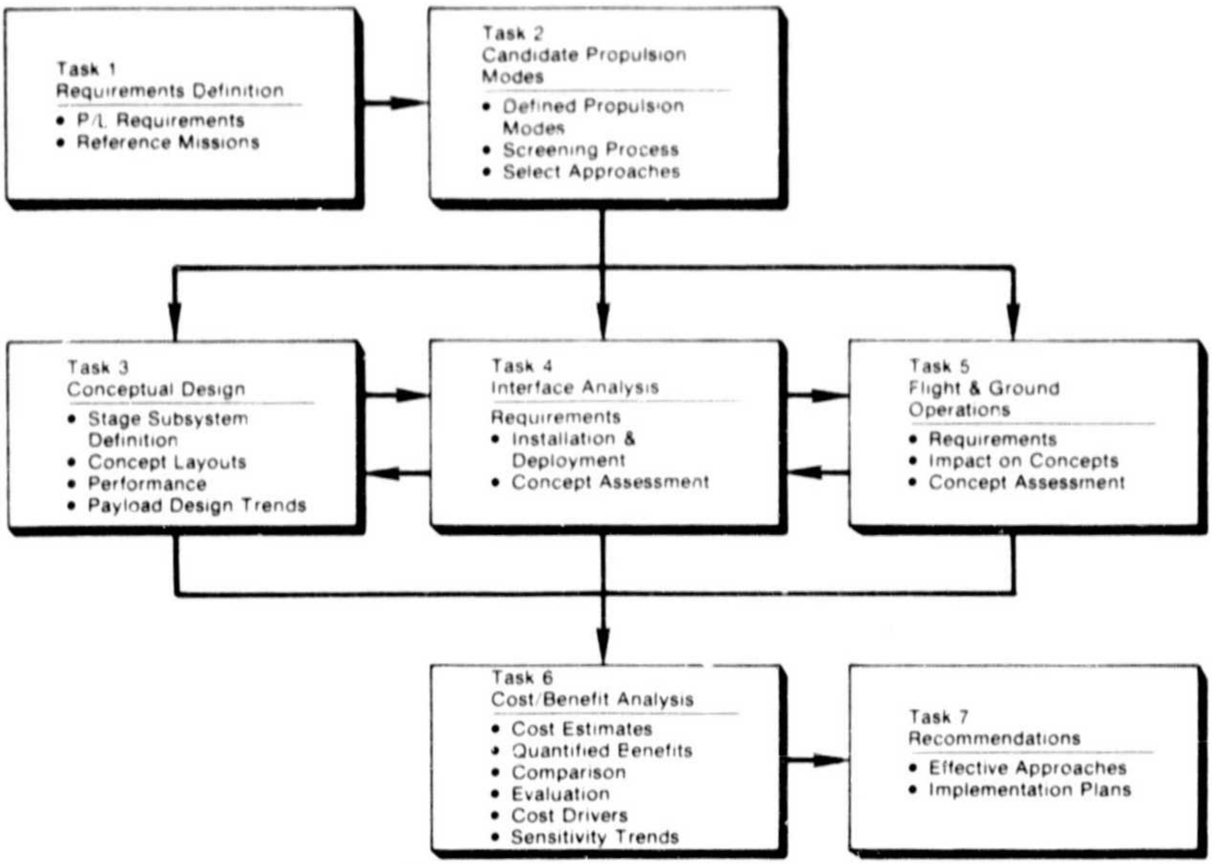


FIGURE 1 STUDY TASK FLOW

In Task 1 the mission model was examined and referenced missions established. The various propulsion modes were established in Task 2 and a preliminary screening performed to reduce the number of approaches to be considered in subsequent tasks. In Task 3 conceptual designs were derived for the more promising new propulsion concepts selected in the Task 2 screening. Interface analysis and flight and ground operations were investigated in Tasks 4 and 5 sufficient to determine the magnitude of the job and the manpower requirements in order to arrive at costs. In Task 6 combinations of the existing/planned Shuttle upper stages were combined with new propulsion concepts to derive the most cost effective way to deliver the payloads of the mission model into the required orbits. Recommendations, schedules, and funding plans were derived in Task 7.

Significant guidelines and assumptions that were used in the study are as follows:

- Mission Model restricted to payloads with energy requirements less than that of SSUS-D. Geosynchronous transfer orbits were excluded.
- Operational period from early 1980's to 1991.
- Investigation was limited to expendable propulsion systems with the exception of the Teleoperator Retrieval System.
- Electrical propulsion systems were excluded from the study.
- Liquid and solid chemical propulsion and hybrid systems were considered in the study. Solid propellants were limited to Class II.
- Space Transportation System physical and operational data were defined by JSC document 07700 Volume XIV, Rev. E.
- Shuttle standard orbital altitude was 296 km (160 n.mi.) and standard inclinations were 28.5°, 56°, 90°, and 98°.
- Study costs were derived in 1977 dollars.
- Shuttle operations begin at the Eastern Test Range in 1980 and at the Western Test Range in 1983.

3.0 PAYLOAD MODEL

The payload model launch schedule, Table 1, for the low energy study incorporates NASA, U.S. Government/Civil, and foreign payloads from the Space Transportation System 487 model applicable to the low energy regime, as well as unclassified low-energy DoD missions and Scout class payloads. The model

TABLE 1 PAYLOAD MISSION MODEL

	Launch Schedule												
Payload Type	80	81	82	83	84	85	86	87	88	89	90	91	Total
NASA			2	5	5	7	3	10	4	7	6	8	57
U.S. Govt/Civil						1	6	3	6	4	6	3	29
Foreign					1	1		2	1	2		4	11
DoD			2	3	2	2	2	2	2	2	2	2	21
Scout Class	3	3	4	1									11
Total	3	3	8	9	8	11	11	17	13	15	14	17	129
ETR Launches			4	4	3	4	3	8	3	7	4	6	46
WTR Launches				4	5	7	8	9	10	8	10	11	72
Scout Launches	3	3	4	1									11

also defined each payload mass, size, and required orbital altitudes and inclinations. The resulting energy requirements for these payloads are defined in the next section on propulsion requirements.

The payloads vary from small automated spacecraft to large free-flying observatories. Destination orbits vary from altitudes of a few hundred kilometers to over several thousand kilometers with inclinations from 2.9 to more than 100 degrees. All the missions had destination orbits above the Shuttle standard orbit and over 60 had orbit inclinations that were different than the Shuttle standard launch inclinations.

4.0 PROPULSION REQUIREMENTS

A mass-velocity map of the energy requirements for the payloads in the payload model is shown in Figure 2. The curved upper limit of the low energy regime shown is the energy capability of the SSUS-D. The vertical line limit is derived as the velocity requirement of 3650 m/sec to deliver a payload to equatorial orbit from the ETR 28.5° inclination launch with a circular orbit altitude of 1111 km. This energy produces an equatorial orbit

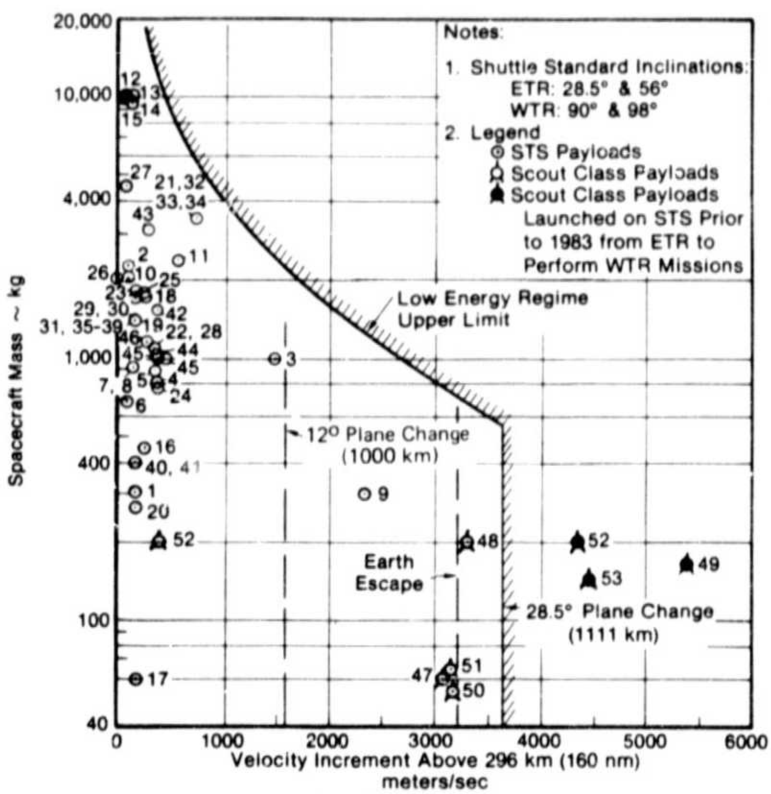


FIGURE 2 LOW ENERGY REGIME

at the lower fringes of the Van Allen Belt and is considered to be a reasonable upper velocity limit for the low energy regime. All other payload inclinations have ΔV requirements less than this 28.5° limit+ when launched from the Shuttle standard inclinations of 28.5°, 56°, 90°, and 98°. The 1983 initial operational date at WTR was considered in establishing these limits as there were no payloads requiring polar type Shuttle launched orbits prior to 1983 except for Scout class payloads.

The velocity requirements for any given payload of the model is that required to transfer from the Shuttle standard orbit to the payload destination orbit altitude and inclination starting at the closest of the four standard Shuttle launch inclinations. The velocity required to deliver each of the payloads of the mission model is plotted in Figure 2 at its corresponding payload mass. The numbers associated with each point are a designation system established early in the study to permit identification of the payloads. Each of the 54 points shown represent a mission payload class with multiple payloads for many of them which result in the 129 payload launches listed in Table 1. Payloads No. 52 and 53, shown as solid points, represent several Scout class payloads launched from ETR into polar orbits and point 49 is a Scout class payload launched into sun synchronous orbit from ETR. The resulting velocity requirements are high but these will be greatly reduced when WTR is operational (e.g., payload No. 52 requires only 400 m/sec from WTR compared to 4300 m/sec if launched from ETR). Approaches to handling these relatively high energy requirements are included in the study.

5.0 CANDIDATE PROPULSION APPROACHES

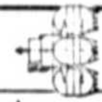
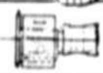
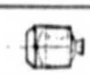
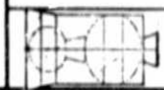
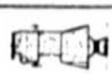
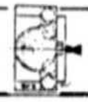
5.1 Candidate Existing/Planned Approaches

Of the five upper stage systems shown in Table 2 that are being considered for the Shuttle, the top 4 were considered in this study, along with the Scout expendable launch vehicle. The 2 and 4-tank versions of TRS were considered in a retrievable mode. The MMS PM-II was considered in expendable mode for those payloads that were designated as MMS payloads. Adaptations of both SSUS-A and SSUS-D were considered. The inertial upper stage (IUS) was much too large for the payloads of the low energy regime and was not considered.

Possible use of the expendable launch vehicle upper stages, shown in the bottom portion of Table 2, were also considered. However, none

appeared attractive for the reasons noted and were not considered further in the study.

TABLE 2 EXISTING/PLANNED APPROACHES

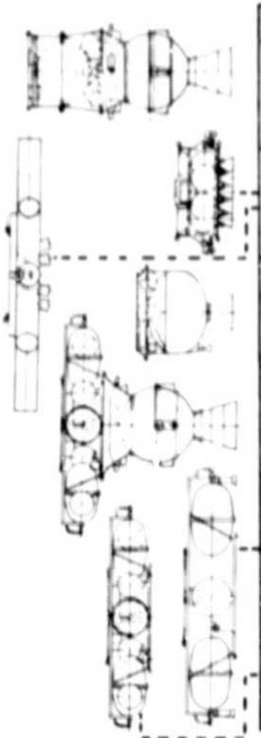
	Upper Stages	Name	Length m(ft)	Dia. m(ft)	Stage Wt. kg(lb)	ΔV (1) m/sec (ft/sec)	Has ACS	Has AKM	Remarks
STS Upper Stages		TRS	2.8 (9.4)	3.048 (10.0)	4153 (9,156)	1000 (3,281)	Yes	Yes	Consider as Retrievable
		MMS/PMII	3.048 (10.0)	2.195 (7.2)	1207 (2,660)	510 (1,673)	Yes	Yes	Consider PM II Module as Expendable
		SSUS-D	2.103 (6.9)	1.402 (4.6)	1936 (4,268)	2452 (8,043)	No	No	Consider an Adaption
		SSUS-A	2.225 (7.3)	1.554 (5.1)	3743 (8,251)	3386 (11,110)	No	No	Consider an Adaption
		IUS (Two-Stage)	4.542 (14.9)	3.170 (10.4)	14,515 (32,000)	6248 (20,500)	Yes	Yes	Too Large for Leo Regime-Not Considered Further
ELV Upper Stages		Burner II A	2,408 (7.9)	1.615 (5.3)	1125 (2,480)	1560 (5,118)	Yes	Yes	None Available; uses H_2O_2-Not Considered Further
		Block 5D	3.444 (11.3)	1.615 (5.3)	2016 (4,444)	2458 (8,064)	Yes	Yes	Long for Energy Compared To Spinning Star 48 - Not Considered Further
		GPS	3.383 (11.1)	1.433 (4.7)	2438 (5,375)	2813 (9,229)	Yes	No	No ACS or G&C; Long for Energy - Not Considered Further
		Satellite Control Section	2.469 (8.1)	3.048 (10.0)	2825 (6,228)	926 (3,038)	Yes	Yes	Bus Concept, Long, Low Mass Fraction - Not Considered Further

(1) Velocity Capability for 1000 kg (2,205 lb.) Payload

5.2 Candidate New Propulsion Approaches

A variety of new propulsion approaches were considered including solids, solid/liquids, and liquids, as shown in Table 3. Some of the advantages and disadvantages of each approach are listed in the table and are summarized in the following comments. Tandem solid stages have high performance and the hardware is available, but long stages would result in higher Shuttle user charges. In addition, the impulses are fixed, resulting in requirement for relatively large numbers of motors and energy management. Efficient packaging of off-the-shelf technology and hardware of clustered solid motors are partially offset by relatively inefficient impulse variability and a potentially serious thrust imbalance problem. Liquid quench and pintle nozzle versions of controlled solid systems were considered because of their inherent efficient packaging, flexibility, and high performance. However, they require considerable development and qualification and represent a technology risk.

TABLE 3 CANDIDATE NEW PROPULSION APPROACHES



System	Advantages	Disadvantages	Remarks	Approaches
Solid/Solid (Tandem)	• High Performance • Off-the-Shelf Technology/Hardware	• Length Inefficient • Poor Impulse Variability	• Disadvantages may be Significant - Consider in Task 2	7
Solid/Solid - Cluster - Flatpack	• Efficient Packaging • Off the Shelf Technology/Hardware • Flexibility	• Thrust Imbalance Problem • Poor Impulse Variability	• Short Stage Length Attractive • Disadvantages are Significant - Consider in Task 2	6
Controlled Solids - Liquid Quench - Pintle Nozzle - Liquid Control	• Efficient Packaging • High Performance • Flexibility	• Development/Qualification Required • High Risk Technology • Capture of Entire Energy Regime Problematical	• High Risk Technology - Consider Liquid Quench & Pintle Nozzle in Task 2 • Liquid Control (Hybrid) Development Much Further Behind — Dropped	3
Solid/Liquid	• Efficient Packaging • Off-the-Shelf Technology/Hardware • Effective Impulse Variability • Flexibility	• More Complex Than Solid/Solid • Liquid System Qualification Required	• Can Cover Entire Energy Regime When Liquid Stage is Used as AKM • Liquid Stage Alone May Cover Large Portion Energy Regime - Consider in Task 2	7
Liquid (Monopropellant)	• Single Stage Simplicity • Single Propellant Simplicity • Effective Impulse Variability	• Low Mass Fraction • Low ISP • More Complex Than Solid • Liquid System Qualification Required	• Use Limited to Low ΔV - Consider in Task 2	6
Liquid (Bi-Propellant)	• Single Stage Simplicity • Effective Impulse Variability • Improved ISP over Hydrazine • Same Propellant as Orbiter RCS	• Moderate Mass Fraction • More Complex Than Solid or Hydrazine • Liquid System Qualification Required	• Large System Required if Sized for High ΔV - Consider in Task 2	6
			TOTAL	35

The liquid control (hybrid) concept is still further behind in development and was not considered. While the disadvantages of a solid/liquid 2-stage concept appears to outweigh advantages, a liquid/solid stage used later in the study showed potential to cover the upper limits of the low energy regime and this configuration was considered. Both monopropellant and bipropellant liquid propulsion concepts were considered.

Despite some of the limitations of these new candidate concepts, a number of approaches for each concept, as shown in the table, were considered. A total of 35 approaches were investigated; in addition, several variations of some approaches were considered resulting in a total of 53 configurations investigated. A conceptual sketch of each configuration was developed in sufficient detail to locate components and subsystems in order to verify weight and balance requirements, to assure a feasible stage, and to determine external dimensions. A weight summary was derived for each configuration. The performance capabilities in terms of ΔV were determined for comparison with the low energy regime requirements.

6.0 INITIAL SCREENING - NEW PROPULSION APPROACHES

6.1 Reference Missions

The new approaches listed in Table 3 were screened in order to reduce the 35 approaches to a more manageable number for later design refinement in Section 7.0, and for comparison with existing/planned systems in Section 8.0. The basis for the screening was a combined cost/risk analysis.

Since all propulsion approaches may not necessarily cover the entire low energy payload regime and also in order to reduce the number of payloads to be considered for each approach, payloads were grouped into six areas as illustrated in Figure 3. Reference Mission payload points (A,B,C,D,E,F) were chosen to represent each area. These points were determined such that

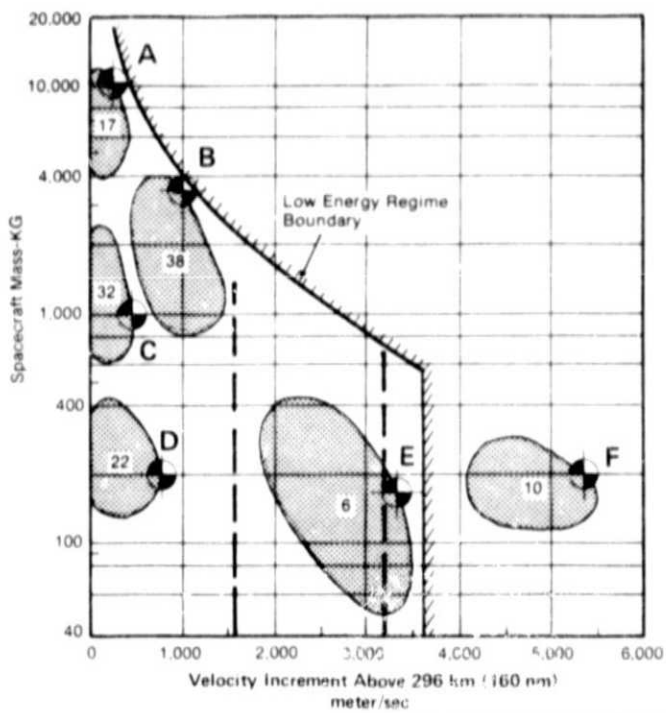


FIGURE 3 REFERENCE MISSION DEFINITIONS

a propulsion concept capturing a given Reference Mission will have sufficient energy to handle the specific payloads within the area. The numbers in Figure 3 indicate the number of payloads included in each area, based on a version of the mission model used early in the study. Typical length, diameter, weight, and orbital characteristics representative of the payloads in each Reference Mission area were derived as shown in Table 4.

TABLE 4 REFERENCE MISSION CHARACTERISTICS

Reference Mission	A	B	C	D	E	F
No. Payloads	17	38	32	22	6	10
Orbit Altitude (km/Incl.)	500/ 28.5°	1000/ 97°	1000/ 57°	577/ 96.5°	1111/ [illegible].9°	1000/ 97.5°
Weight — kg	10000	3000	1000	200	170	200
Length — m	13.5	9	3	1.8	1.8	1.8
Diameter — m	4.5	4	4.5	1.4	1.4	1.4

6.2 First Screening

With this simplification, the capability of the new propulsion approaches to meet the energy requirements of each Reference Mission was determined. Costs were estimated for each approach consisting of the stage unit production cost plus the Shuttle user charge for the stage and payload. For simplicity in this first screening analysis the development, program maintenance, operational, and ASE costs were not assessed. The stage unit costs were built up from subsystem estimates based largely on the RCA PRICE costing system along with vendor quotes and Vought experience. The Shuttle user charges for the stage and payload were taken from the STS Users Handbook escalated to 1977 dollars with a resulting $21.83M charge per dedicated Shuttle launch. The user charge for each stage and payload were then determined using a 75% load factor and length or weight, whichever was critical. A summary of the costs to launch each Reference Mission payload for the various propulsion approaches considered is shown in Table 5 ranked by cost order.

6.3 Second Screening

Table 5 shows that the lowest cost approach for each Reference Mission is a different system which would entail undesirable development of many systems. It is noted that the cost differential of the top six or eight approaches for each Reference Mission is not great. Accordingly, all of the upper ranked approaches were examined to determine which logical combinations of systems might satisfy all Reference Missions. One such typical combination, shown in the heavy outlined boxes, might be some version of a liquid system together with a SSUS-D or SSUS-A for the higher energy Reference Missions E and F. Another might be the modular solid flatpack for the lower energy missions together with a SSUS-D/STAR 37F for the high energy mission.

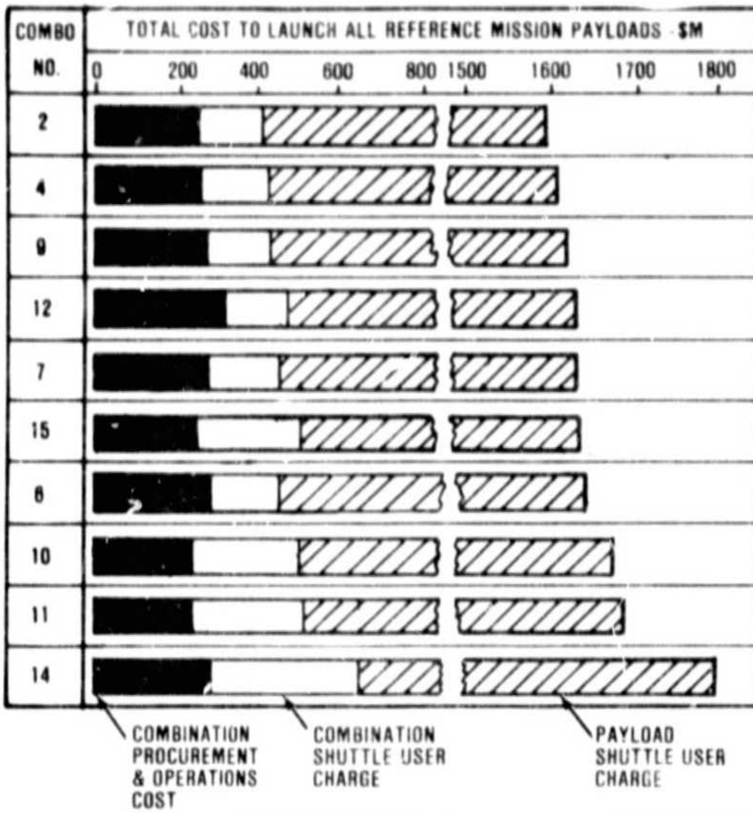
TABLE 5 COST RANKING FOR PROPULSION APPROACHES

REFERENCE MISSION	A		B		C		D		E		F	
COST ORDER	APPROACH	COST $M	APPROACH	COST $M	APPROACH	COST $M	APPROACH	COST $M	APPROACH	COST $M	APPROACH	COST $M
1	INTEGRAL OMS	21.48	FLAT PACK 6-LONG	16.61	4 T-MONOPROP	6.85	STAR 17A/ STAR 17 (V)	3.24	LIQUID QUENCH (V)	3.81	S. SSUS-D/ S.STAR 37F	9.51
2	6 T-BIPROP	23.53	8 TANK BIPROP (MODULAR)	16.88	FLAT PACK 4 SHORT	6.88	4 STAR 17 (V)	3.33	PINTLE-LARGE (V)	3.82	SSUS-D/ STAR 37F	9.97
3	8 T-MONOPROP	23.54	8 T-MONO-PROP (MODULAR)	17.13	4 T-BIPROP A	6.89	STAR 26/ STAR 26 (V)	3.75 (W)	S.STAR 37F/ S.STAR 37S (V)	4.10 (W)	SSUS-A/ 8T-BIPROP (MODULAR)	10.34
4	8 T-BIPROP	23.55	LIQUID QUENCH	17.89	4 T-BIPROP B	6.91	PINTLE-SMALL (V)	3.78 (W)	8 T-BIPROP (MODULAR)	5.23		
5	FLAT PACK 6 SHORT	23.60	PINTLE-LARGE	18.07	4 T-BIPROP (MODULAR)	6.98	3 T-MONO-PROP	4.71	S. SSUS-D/ 4 T-BIPROP (V)	5.68		
6	4 T-BIPROP (MODULAR)	23.78	22 STAR 17	[illegible]	2 TANK MONO-PROP (MODULAR)	7.07	4 T-BIPROP (V)	4.86	STAR 37E/ 4 T-BIPROP (V)	5.86		
7	4 T-MONOPROP (MODULAR)	24.00	STAR37E/ 6T-BIPROP	19.17	4 STAR 17	7.11	FLAT PACK 4 SHORT	4.98	S. SSUS-D/ 2 T-MONO-PROP (V)	5.93		
8	7 STAR 17	24.19	S. SSUS-D/ 4 T-BIPROP	19.23	PINTLE-SMALL	8.06	4 T-BIPROP	5.08	22 STAR 17 (V)	6.59		
9	PINTLE-SMALL	24.90	S. SSUS-D/ 4T-MONOPROP	19.33	LIQUID QUENCH	8.20	4 T-BIPROP (MODULAR)	6.20	SSUS-D/ STAR 26	8.87		
10	LIQUID QUENCH	24.95	S.STAR 37F/ S.STAR 37S	19.60	PINTLE-LARGE	8.45	2 T-MONO-PROP (MODULAR)	5.15	SSUS-D/ 4 T-BIPROP (MODULAR)	8.88		
11	PINTLE-LARGE	25.16	SSUS-D/ STAR 26	20.58	STAR 17A/ STAR 17	8.57	LIQUID QUENCH (V)	5.66(W)	S. SSUS-D/ S.STAR 37S	8.89		
12	STAR 26/ STAR 26	25.78	S. SSUS-D/ STAR 37S	20.38	STAR 26/ STAR 26	8.90	PINTLE-LARGE (V)	5.74(W)	S. SSUS-D/ S.STAR 37F	9.51		
13	SSUS-D/ 2T MONOPROP	26.45	S. SSUS-D/ S.STAR 37F	20.95	S. SSUS-D/ S.STAR 37	10.82	S. SSUS-D/ S.STAR 37	8.89	SSUS-D/ STAR 37F	9.97		
14	SSUS-D/ STAR 26	27.43	SSUS-D/ STAR 37	21.43	SSUS-D/ STAR 26	10.84	SSUS-D/ STAR 26	8.92				

V - INDICATES CONFIGURATION IS INSTALLED VERTICALLY. ALL OTHERS ARE INSTALLED HORIZONALLY
W - INDICATES SHUTTLE CHARGE IS DETERMINED BY WEIGHT. ALL OTHERS ARE DETERMINED BY LENGTH
T - INDICATES NUMBER OF TANKS FOR LIQUID SYSTEMS
S - SHORT NOZZLE

The Orbiter with its integral OMS tanks was included in the majority of the combinations because it provides the most economical means for launching the large observatories and telescopes associated with Reference Mission A. Some of the lower cost combinations are listed in the right hand column of Figure 4.

Costs for each combination were determined using a somewhat greater in-depth costing procedure. The unit costs previously used were adjusted for quantity buys based on the number of payloads each combination can handle. The development costs of stage and ASE and the program maintenance costs were also added. The flight operations and GSE costs were not expected to be greatly different for the various approaches and were not included. The costs were accumulated as total program costs, i.e., the sum of development costs, unit cost times the number of payloads captured by each approach, and the annual sustaining costs times years of operation. The resulting program costs for the top ten propulsion approach combinations are cost ranked in bar chart form in Figure 4.



COMBO NO.	COMBINATION DESCRIPTION			
2	INTEGL OMS	4 OR 8T MOD. BIPROP	8 T MOD. BIPROP/ SSUS-A	—
4	INTEGL OMS	MOD SOLID FLAT PACK	S. SSUS-D/ S. STAR 37F	—
9	INTEGL OMS	4 OR 8T MOD. BIPROP	4T MOD BIPROP/ SSUS-D	8T MOD BIPROP/ SSUS-A
12	INTERL OMS	MOD. STAR 17 CLUSTER	S. SSUS-D/ S. STAR 37F	—
7	INTEGL OMS	2 OR 8T MOD. MONOPROP	S. SSUS-D/ S. STAR 37F	—
15	INTERL OMS	PINTLE (Large/Small)	S. SSUS-D/ S. STAR 37F	—
8	—	4 OR 8T MOD BIPROP	4T MOD BIPROP/ SSUS-A	—
10	INTEGL OMS	LIQUID QUENCH	S. SSUS-D/ S. STAR 37F	—
11	INTEGL OMS	PINTLE (Large)	S. SSUS-D/ S. STAR 37F	—
14	INTEGL OMS	SSUS-D/ S. STAR 37F	STAR 17A/ STAR 17	—

S. - SHORT NOZZLE
T - NO. TANKS

FIGURE 4 COST COMPARISON OF PROPULSION APPROACH COMBINATIONS

Approximately 25% of the total costs of a given combination are directly a function of the propulsion approach with 75% attributable to the Shuttle user charge for the payloads. The propulsion approach costs amount to about $420M for the lowest cost combination number 2. Costs within 10% of this were considered to be essentially equal and therefore a benefits analysis was performed for those combinations falling within this band to adjust the ranking for final selection of the propulsion approaches. The new propulsion approaches selected for benefits analyses were the modular monopropellant, the modular bipropellant, the flatpack, and the clustered Star 17.

6.4 Risk/Benefits Analysis

Mission capture, accuracy, and risk were the benefit factors evaluated for these four lower cost propulsion approaches. The modular monopropellant and the modular bipropellant ranked high in benefits and were the top choices for new propulsion approaches. The flatpack and the clustered solids suffered because of greater development risk compared to liquid systems due to potential unsymetrical multi-motor thrust alignment and thrust buildup, and reliability of multi-motor arrangements.

The initial screening of the new propulsion approaches is summarized in Figure 5. As indicated, the modular monopropellant and modular bipropellant were selected for conceptual design in Section 7.0. Also carried forward into conceptual design were the SSUS-D and SSUS-A adaptations as first stage perigee kick boosters.

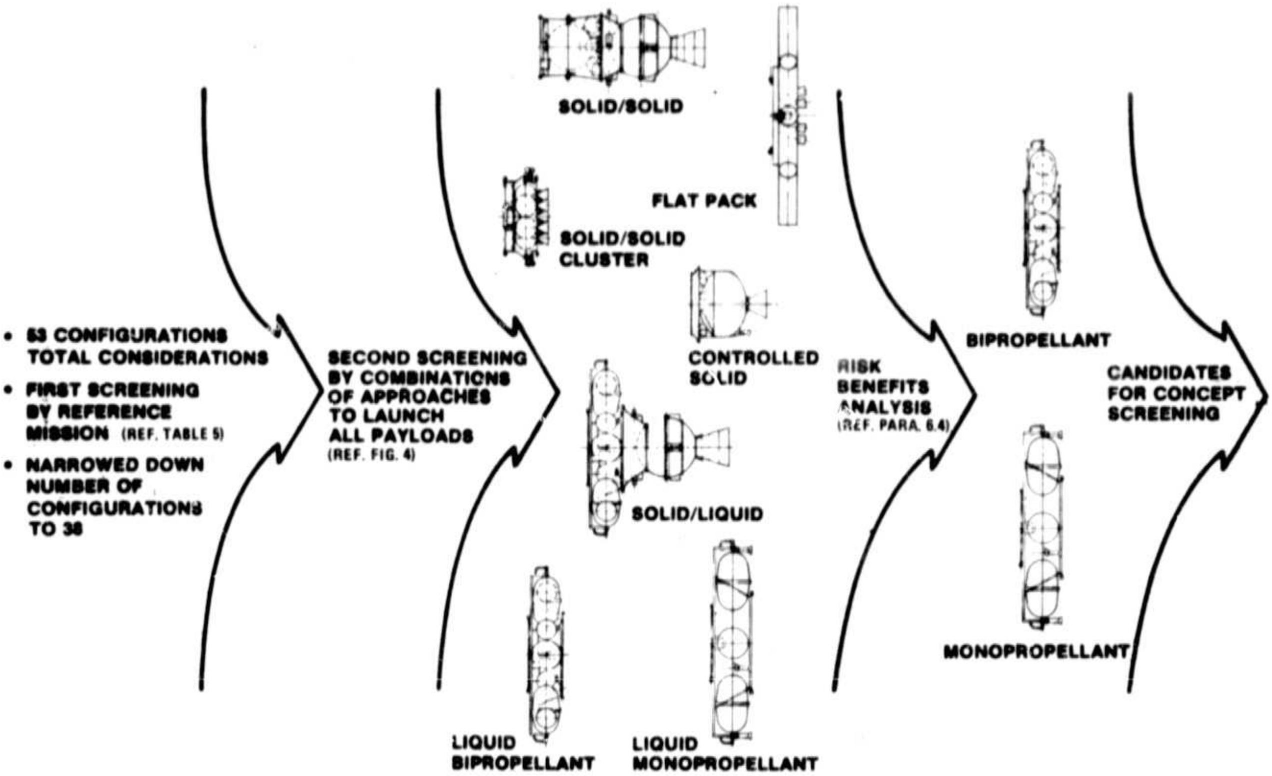


FIGURE 5 INITIAL SCREENING OF PROPULSION APPROACHES

7.0 CONCEPTUAL DESIGN

The selected bipropellant and monopropellant approaches were refined and conceptual designs established. The primary efforts addressed were refinement of the subsystems and conceptual design of an operational system for each of the selected concepts. The feasibility of using the propulsion system in an integrated payload/propulsion mode was also assessed.

7.1 Refinement of Subsystems

In this phase of the conceptual design of the bipropellant and monopropellant stages each of the major subsystems was reviewed in greater depth than in the conceptual sketches derived in Section 5.2. A summary of the major subsystem characteristics is presented in Table 6 and discussion of some of the highlights is given in the paragraphs below.

TABLE 6 SUBSYSTEM CHARACTERISTICS

	BIPROPELLANT	MONOPROPELLANT
STRUCTURE	MODULAR TUBULAR, ALUMINUM, OPEN TRUSS. MODULARITY PERMITS ASSEMBLING 2,4, AND 8 TANK VERSIONS.	
FUEL	N_2O_4 / MMH	N_2H_4
MAIN THRUSTER	1 - MARQUARDT R - 40A 3880N (872 lb_f) (SHUTTLE RCS MOTOR)	4 - ROCKET RESEARCH CORP MR 104 623N (240 lb_f) EACH JUPITER/SATURN 77 RCS MOTORS
SYSTEM SPECIFIC IMPULSE	2746N · sec/kg (280lb_f · sec/lb_m)	2157N · sec/kg (220lb_f · sec/lb_m)
RCS SYSTEM	4 - MARQUARDT R -4D 445N (100lb_f) (APOLLO/LEM MOTORS)	SEQUENTIAL MODULATION OF MAIN THRUSTERS
PRESSURANT TANKS	PRESSURE SYSTEMS, INC. STANDARD SPHERICAL TANKS	LARGER TANKS THAN STANDARD SIZES REQUIRED
PROPELLANT TANKS	ARDE CONOSPHERICAL, RING STABILIZED, METAL DIAPHRAGM POSITIVE EXPULSION	
DATA SYSTEM	CONIC MODEL 8 WATTS - BAND TRANSMITTER WITH 4 OMNI DIRECTIONAL TECOM INDUSTRIES, INC. ANTENNAS	
GUIDANCE SYSTEM	INERTIAL STABLIZATION UNIT (THREE - AXIS SYSTEM)	
THERMAL PROTECTION	MULTI-LAYER INSULATION BLANKET COVERS VEHICLE. THERMAL CONDUCTION RADIATOR COOLS THE TRANSMITTER. INSULATED TITANIUM SHIELDS FOR THRUSTER PLUME PROTECTION. HEATERS FOR THRUSTERS.	
POWER SYSTEM	AUTOMATICALLY ACTIVATED 600 WATT HOUR SILVER ZINC BATTERY	
IGNITION CONTROL	IGNITION CONTROL UNIT CONTAINS FIRING CAPACIT SWITCHING, TRANSISTORS, SAFE/ARM RELAYS	

Modular Structural Concept

The modular structural design illustrated in Figure 6 lends itself to a stage system that can be adapted to a wide variety of payload sizes, shapes and velocity requirements by varying the number of tanks. The aluminum, truss structural arrangement is efficient and provides easy access to components. The system baseline, shown in Figure 7, is the eight-tank version used for relatively heavy payloads or to meet the higher velocity requirements. The four outer modules, made up of propellant and pressure tankage, plumbing, and electrical connections, are removed and the end plate supports, transmitter and antennae are relocated to produce the same length four-tank version for horizontally mounted payloads. Relocation of the upper and lower oxidizer tank modules on an auxiliary structural frame produces a four-tank vertically mounted version. This approach is illustrated in Figure 8 for the bipropellant stages. The monopropellant approach is similar. In addition the symetry of monopropellant propulsion tankage systems permit assembling a two tank version to accommodate payloads with very low energy requirements.

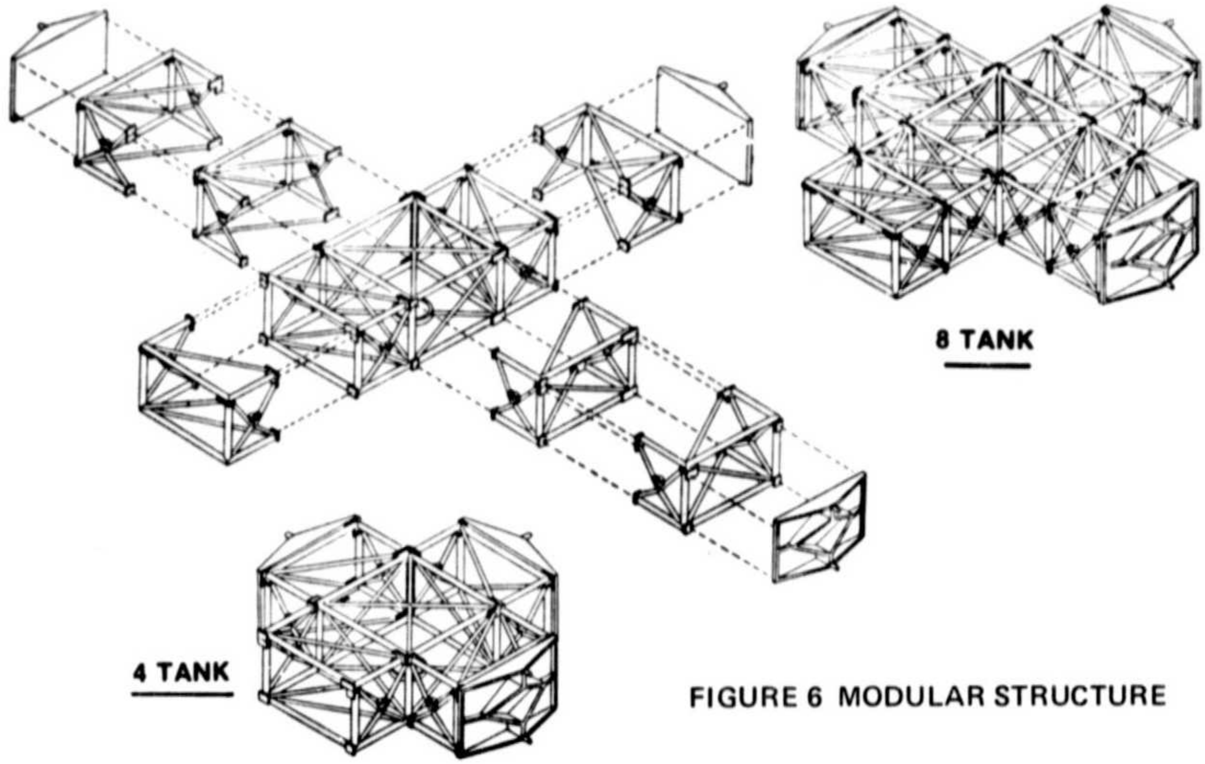


FIGURE 6 MODULAR STRUCTURE

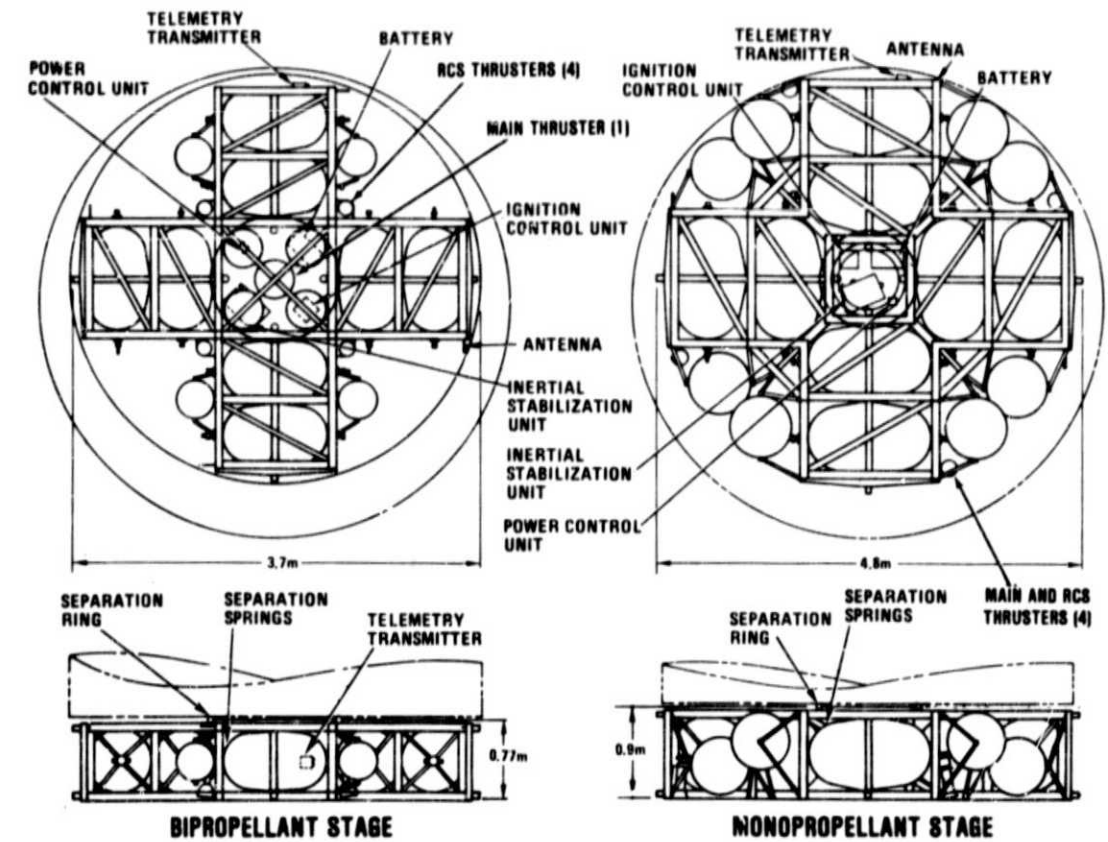


FIGURE 7 EIGHT-TANK BIPROPELLANT AND MONOPROPELLANT STAGES

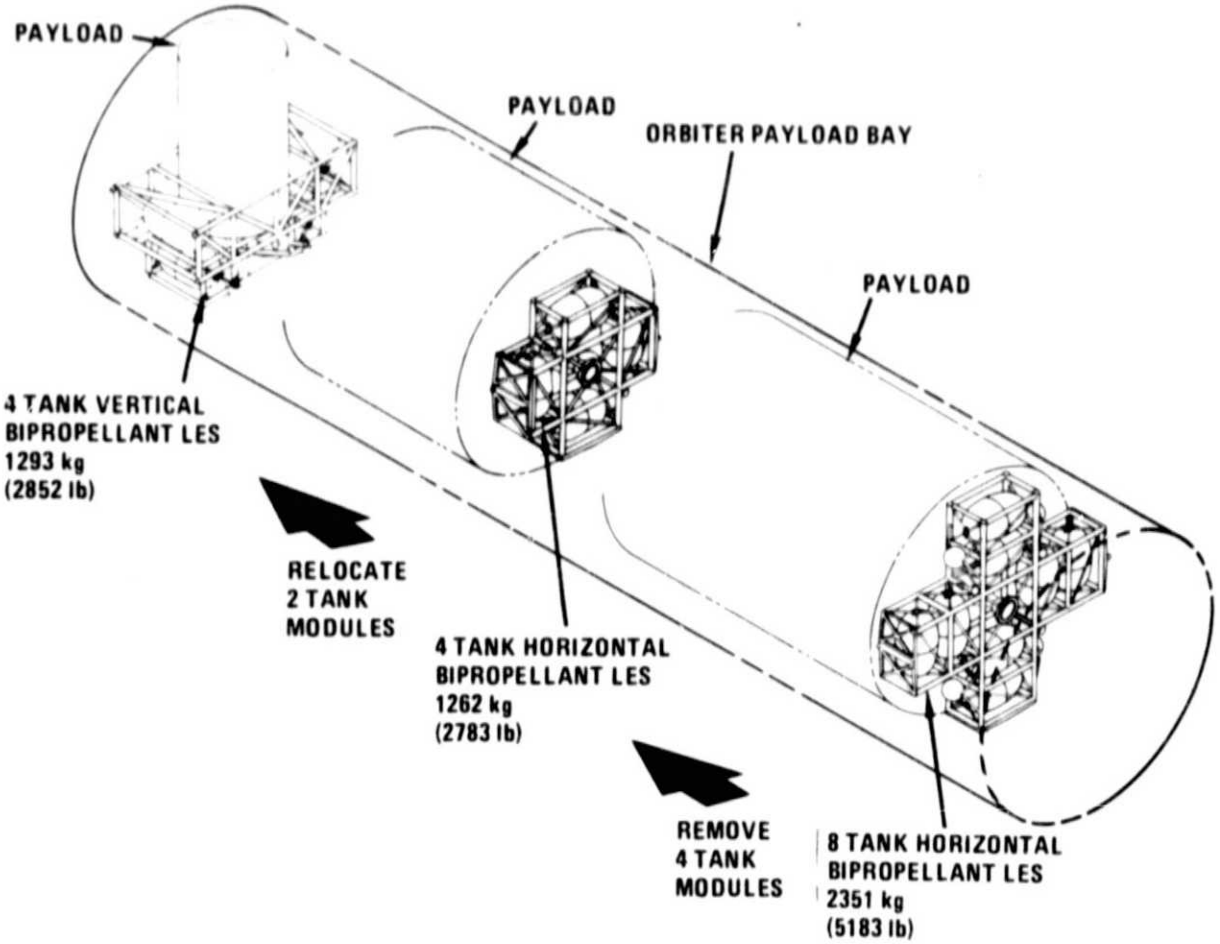


FIGURE 8 MODULAR BIPROPELLANT SYSTEM

To accommodate the higher energy payloads, an adaptation of the four-tank vertical versions of the low energy stage system to the SSUS-D for vertical installation in the Orbiter cargo bay can be made. This is illustrated in Figure 9 for the bipropellant 4-tank vertical stage. This approach allows the design of the basic modular system to better match the lower region of the regime occupied by the majority of the payloads of the model and yet be adaptable to the higher energy missions with little modifications. Adaptation of the four-tank vertical version of the bipropellant stage to the SSUS-A for horizontal installation in the Orbiter cargo bay is also shown in Figure 9. Similar adaptations of monopropellant stage systems to the SSUS-A and SSUS-D were also established. Sufficient reaction control authority was provided to fly the SSUS-A and SSUS-D adaptation in a non-spinning 3-axis stabilized mode.

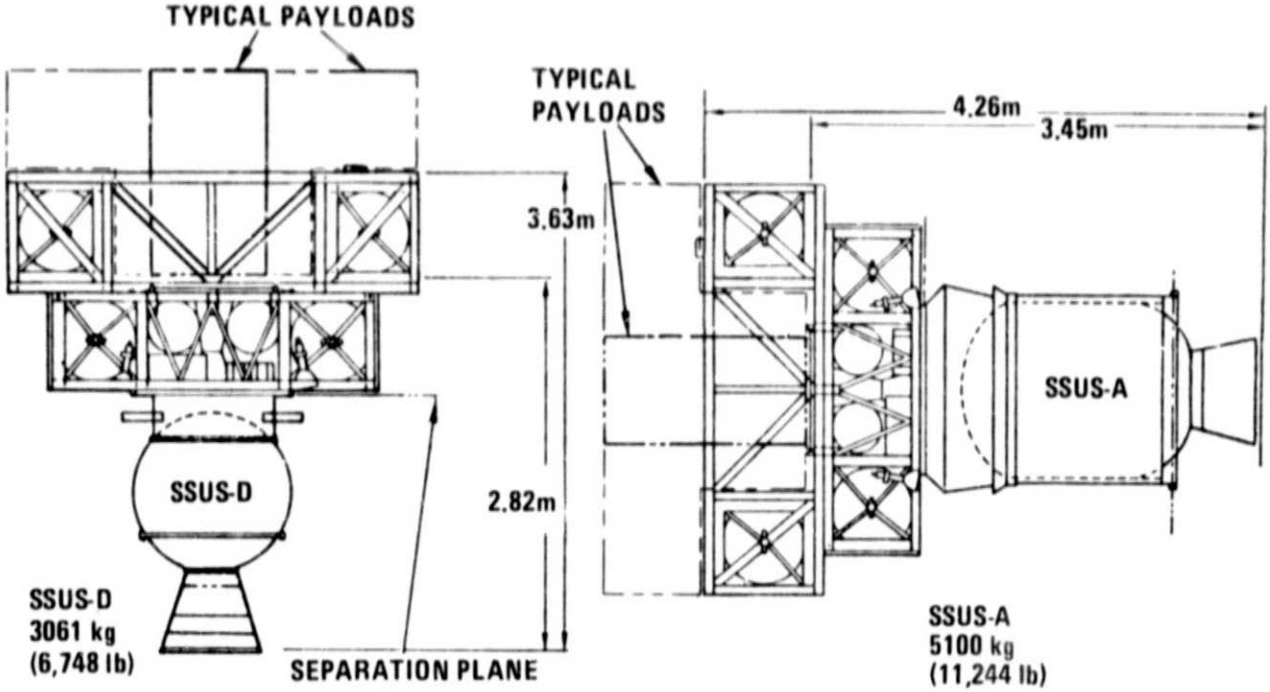


FIGURE 9 FOUR TANK BIPROPELLANT SSUS ADAPTATIONS

Propulsion System

The design philosophy for the modular approach dictated as much commonality as practical between the different versions as well as the use of as much qualified and existing hardware as possible, as indicated in Table 6. The most critical energy requirements occurred in the 8-tank payload groups, thus establishing propellant tank volume and hence physical size of the vehicle. This same tank size was used for the 4-tank and two-tank vehicles. Bipropellant vehicles with only 2 propellant tanks were not considered due to the center of mass variation produced as fuel and oxidizer of different specific weights are consumed. However, 50 percent propellant off-load conditions were used for the very low energy bipropellant performance and cost comparisons. The prepackaged propellant tanks were considered to be loaded at the propellant manufacturer's loading facility and delivered direct to the launch site in either 100 or 50 percent loaded condition as required for the scheduled launch.

Guidance System

A 3 axis stabilization system with RCS control was chosen for several reasons. First the majority of the payloads prefer not to be spun. Also, the accuracy requirements of transfer and orbit insertion would be difficult to meet with spinning systems. Ground checkout, balance, ASE, and

deployment from the Shuttle are mechanically simplier with a 3 axis stabilized system. The type of guidance used in the study was a 3 axis strapdown system with a computer and is of a type similar to that considered for development for the Scout launch vehicle.

7.2 Weight Summary

The weights of principal configurations of the monopropellant and bipropellant stages are summarized in Table 7 along with principal dimensions of each stage.

TABLE 7 WEIGHT SUMMARY — kg (lb)

	MODULAR BIPROPELLANT		MODULAR MONOPROPELLANT	
	8 - TANK HORIZ	4 - TANK HORIZ	8 - TANK HORIZ	2 - TANK HORIZ
STRUCTURE	123	100	152	106
PROPULSION				
— TANKAGE & PLUMBING	473	247	871	245
— RCS THRUSTERS	10	10	—	—
— MAIN THRUSTERS	10	10	10	10
GUIDANCE & CONTROL	21	21	21	21
DATA MGMT &COMM	3	3	3	3
POWER SYSTEM	28	28	30	24
IGNITION CONTROL	6	6	6	6
TOTAL INERTS	674	425	1093	415
CONSUMABLES	1677	837	2412	594
STAGE IGNITION	2351	1262	3506	1009
	(5183)	(2783)	(7729)	(2224)
LENGTH — m	0.77	0.77	0.88	0.88
DIAMETER — m	3.96	2.69	4.11	2.62

7.3 Performance

Modular Bipropellant

Performance capabilities of this low energy stage system are shown in Figure 10 compared to the requirements of the payload model and the low energy regime boundary. Capabilities of the horizontally mounted 4-tank versions are shown with full fuel and with fuel off-loaded to 50% capacity which is sufficient for many of the very low energy missions. The 4 and 8 tank versions of the bipropellant stage can cover a large portion of the low energy regime and capture all but four of the mission model points (7 payloads). With the 4-tank version mounted on the SSUS-A and -D, the remainder of the low energy regime can be covered which permits delivery of

all payloads except No. 49 - the Solar Mesosphere Explorer to be placed into a sun synchronous orbit in 1981 from ETR. As will be shown later, it is more economical to deliver this and other Scout class payloads with the Scout launch vehicle prior to Shuttle becoming operational at WTR. Capabilities of the three basic versions of the modular system (without SSUS-D or -A) encompass 85% of the low energy regime area and cover all of the payload model requirements after 1983 when WTR is operational.

Modular Monopropellant

Comparable performance capabilities of the monopropellant stage system are shown in Figure 11. The two-tank and eight-tank versions accommodate all but 8 of the missions points (12 payloads) of the payload model. After 1983 the capabilities of these monopropellant stages encompass the requirements of all of the payloads of the model. If future payloads emerge having higher energy requirements, an adaptation of the 2-tank version to the SSUS-D and SSUS-A will encompass essentially the entire low energy regime.

7.4 Integral Propulsion

A special task was conducted to investigate the use of an integral propulsion system which would depend on the spacecraft to provide common functions of guidance and attitude control commands, power, communications and data handling. This approach would permit removing these functions from the basic stage. Three options were selected to scope the potential cost variances. Options selected for this investigation were: (1) one propulsion system design tailored to the mission requirements of the payload model and attached to the spacecraft structure; (2) several propulsion system designs, each tailored to a specific class of the payload model requirements and attached to the spacecraft structure; (3) propulsion systems provided by a spacecraft contractor with propulsion and spacecraft components integrated into a common structure.

The cost variance estimates for these options included the impact on the spacecraft as well as the stage. Some stage cost reductions were offset by increased spacecraft contractor responsibility because the supporting cost cannot be eliminated from the program. These supporting costs are: integration, documentation, interface control, integrated test and simulations, training, management, ground support equipment and operations support cost. The cost for these items were escalated because they will not be a

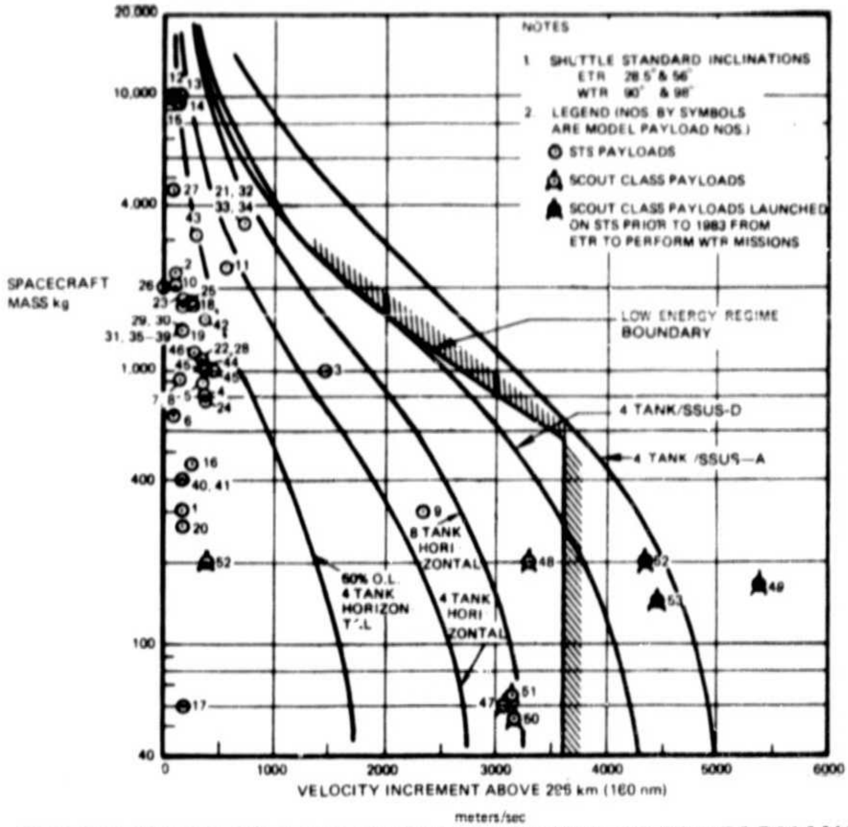


FIGURE 10 MODULAR BIPROPELLANT STAGE PERFORMANCE

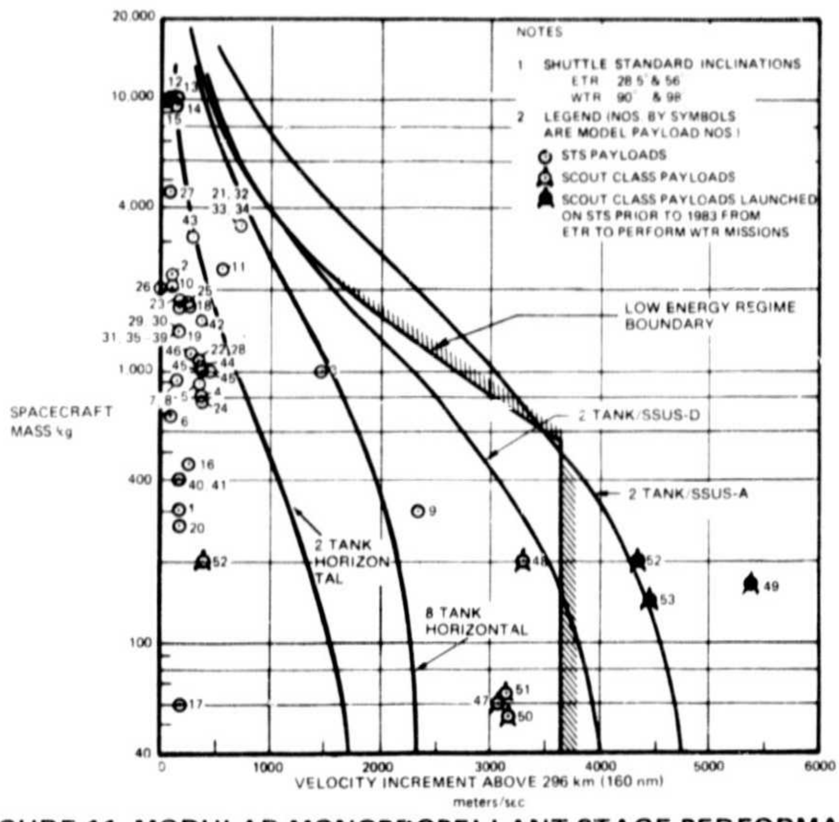


FIGURE 11 MODULAR MONOPROPELLANT STAGE PERFORMANCE

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common one-time expense with many spacecraft contractors involved. For this task 31 spacecraft types (103 spacecraft total) requiring a low energy stage for transport from the Shuttle orbit to the spacecraft operational orbit were selected from the payload model of Table 1.

With these considerations, the following trend results present a comparison of the options based on the use of a bipropellant low energy stage propulsion system. Option one, a potential cost savings of $102M to the stage and a potential cost increase of $82M to the spacecraft for a net potential savings of $20M. Option two showed that cost reduction to the stage was equal to the cost increases for the spacecraft. The savings for options one and two do not consider that some planned spacecraft may not include, as a basic spacecraft design requirement, equipment that will provide the necessary guidance, power and data functional requirements. Option three showed a potential cost increase of $540M due primarily to the proliferation of the large number of different spacecraft manufacturers integrating and producing their own propulsion systems.

While there are some cost savings indicated with option one, the risk of some spacecraft not having the required functions available could easily off-set this advantage. As a result, the integrated propulsion system approach was not considered further in the remainder of the study.

7.5 Airborne Support Equipment (ASE) Conceptual Design

The spectrum of payload sizes to be accommodated by the ASE is shown in Figure 12. It is apparent that it is possible to cantilever only the smaller size payloads from the stage. Both existing/planned cradles, as well as new concepts were examined for compatibility and adaptability to the stage/payload requirements. Applicable existing/planned cradle concepts considered are shown in Figure 13 along with the percent of the payload model which each cradle can accommodate. Since less than 50% of the payload model could be accommodated by any of these cradles and since, without extensive redesign, the larger eight tank versions of the modular stage concepts would not adapt to these cradles, a new modular cradle concept was developed.

An evaluation of Shuttle user charge policy and stage and payload characteristics established the following cradle design and cost drivers.

- o Cradles should not add length to stage/payload combination
- o Weight should be minimized

- Cradles should accommodate a broad range of payloads
- Cradles should permit deployment of payload/stage without additional Orbiter bay length requirement

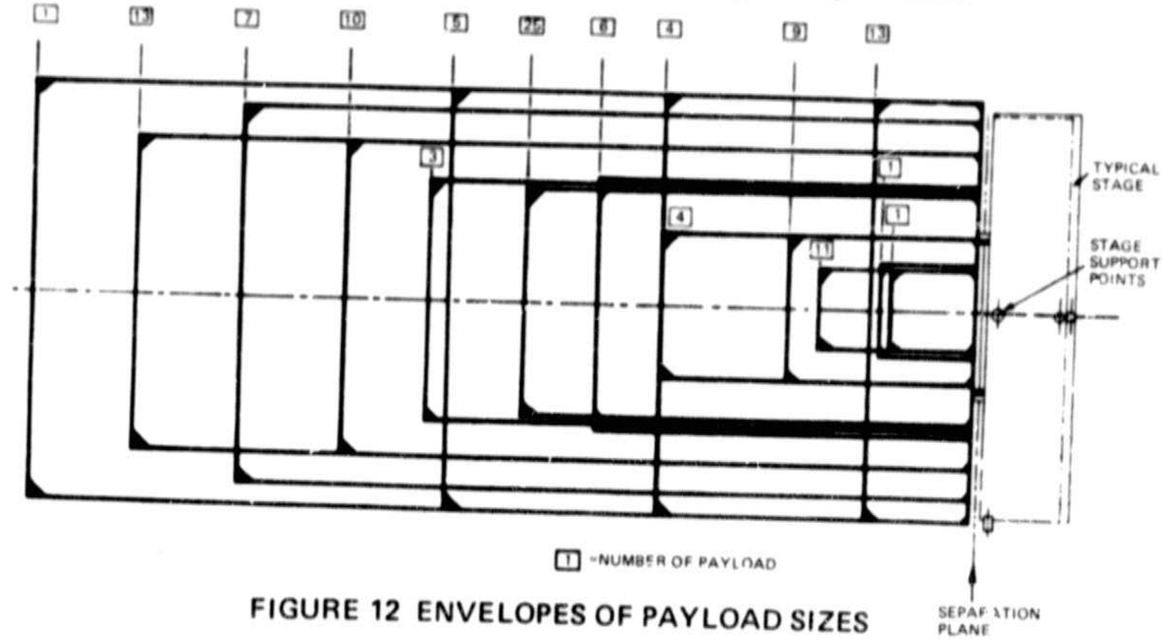

FIGURE 12 ENVELOPES OF PAYLOAD SIZES

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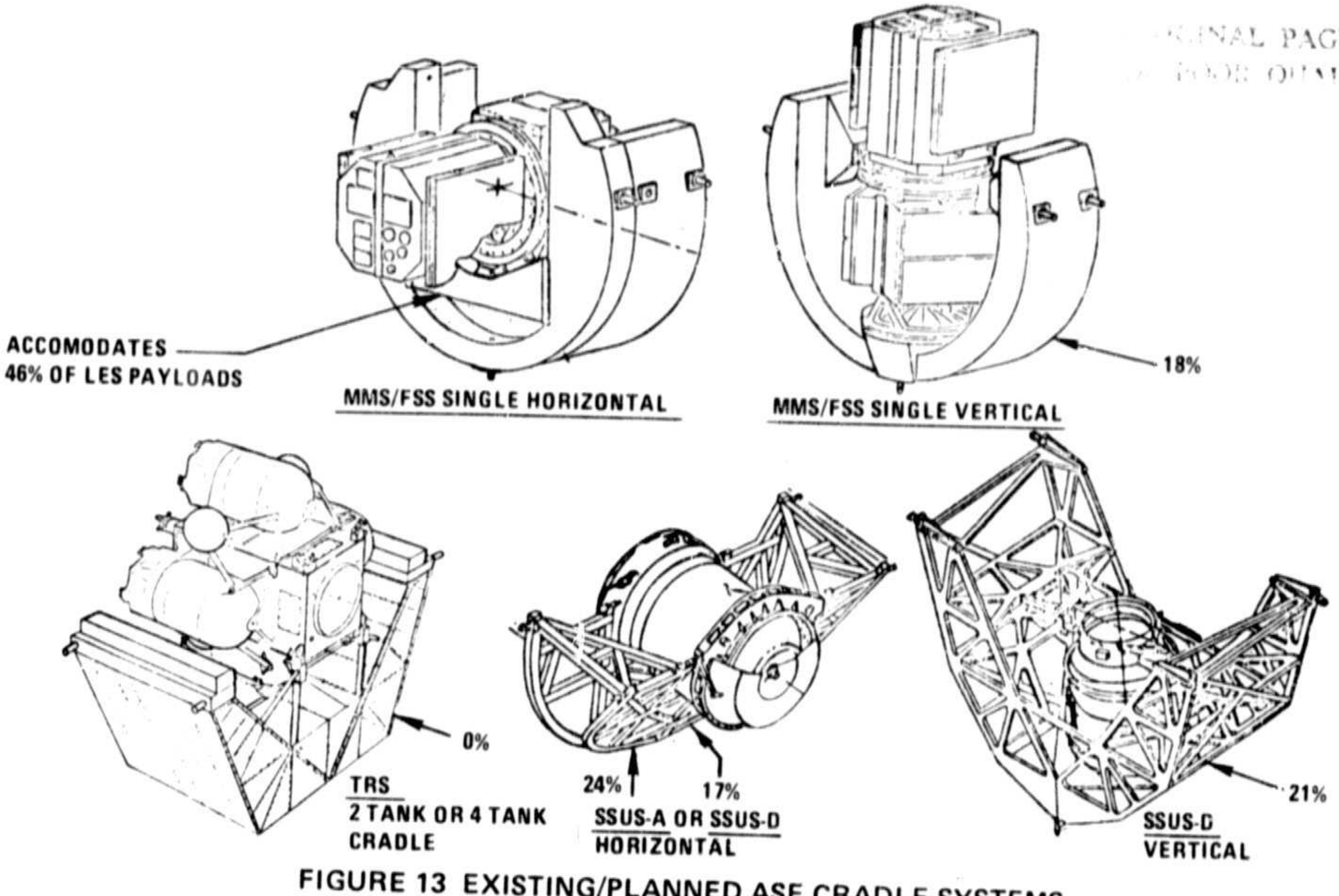

FIGURE 13 EXISTING/PLANNED ASE CRADLE SYSTEMS

7.5.1 Modular Cradle Concepts

The basic modular cradle concept derived (Figure 14) accommodates payloads up to 9 m long, 4 m in diameter, and 4500 gk mass in both horizontal and vertical arrangements. The larger payloads of the telescope class would be self mounted with the stage attached on the end of the spacecraft. The ASE concept is modular such that the components can be arranged in assemblies to support a broad spectrum of payloads with 4-tank or 8-tank LES stages in a horizontal arrangement and the 4-tank version in the vertical position. The assembly components consist primarily of fore and aft cradle units on each end, a walking beam, and intermediate adjustable rod assemblies. Deployment mechanisms - either mechanical springs or motor-driven scissors-jack electromechanical units - are located under the combined center of gravity of the payload plus stage. The Remote Maneuvering System (RMS) can also be used for deployment. Typical payload and stage arrangements with the 8- and 4-tank horizontal and 4-tank vertical cradle assemblies are shown in Figure 15. This cradle system supports the spacecraft and stage as a unit throughout Shuttle launch and payload deployment. The stage is separated from the spacecraft after delivery to the desired orbit. This support concept does require a strong point on the spacecraft approximately at the center of gravity. This is not considered to impose a severe restraint on spacecraft design since most of them have not been designed in detail and will require some mode of support in any event.

The SSUS-D and SSUS-A cradles were found to be compatible with the modular stage adaptations as shown in Figure 16. The only modification required to the SSUS cradles is to deactivate the spin table functions. Deployment would utilize the existing SSUS mode of spring separation or the RMS.

7.5.2 Avionics Airborne Support Equipment

Typical control, display and avionic ASE that provides interface of stage/cradle assembly/avionics to the payload accommodations equipment consists of the following equipment:

- Control and Monitor Panel
- Cradle Power Control Unit
- Cradle Signal/Data Interface Unit
- Cradle Deployment Mechanisms Unit
- High Gain Antenna and Receiver

- Cable Plant and Cradle Harnesses

The controls, displays, avionic ASE and cable harness integration and interfaces with payload accommodations equipment are shown in Figure 17.

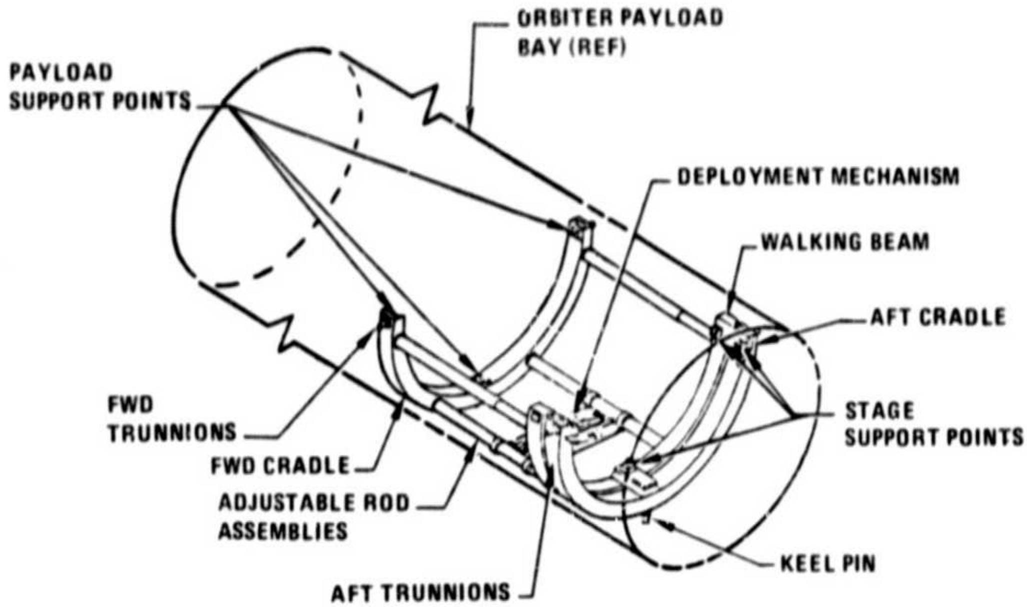

FIGURE 14 ASE CRADLE CONCEPT

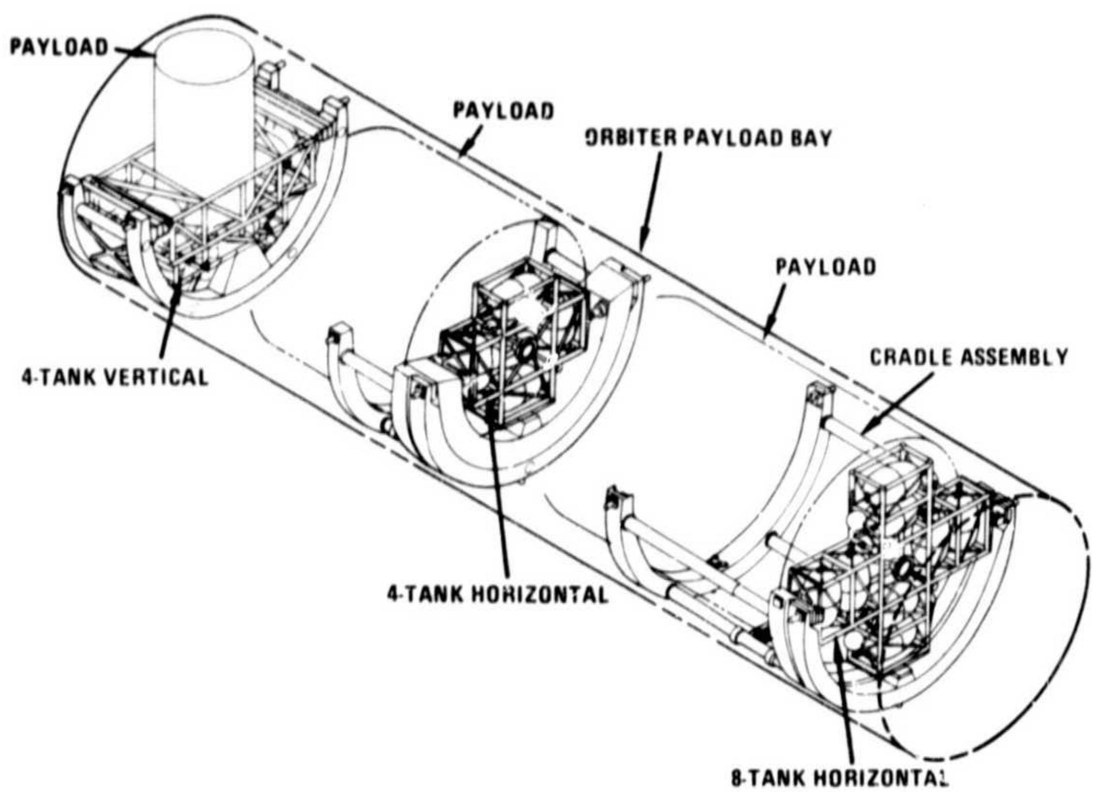

FIGURE 15 MODULAR STAGE/ASE INSTALLATION

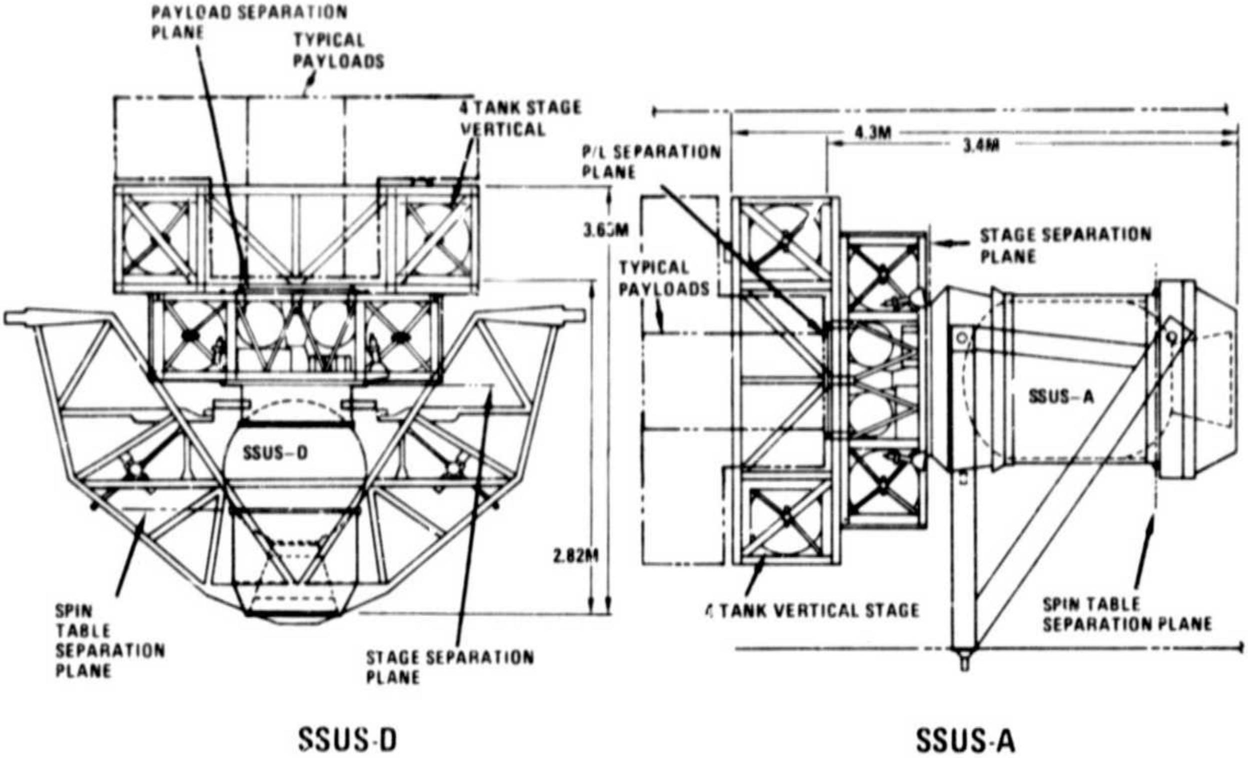

FIGURE 16 FOUR-TANK STAGE ADAPTATIONS TO SSUS ASE

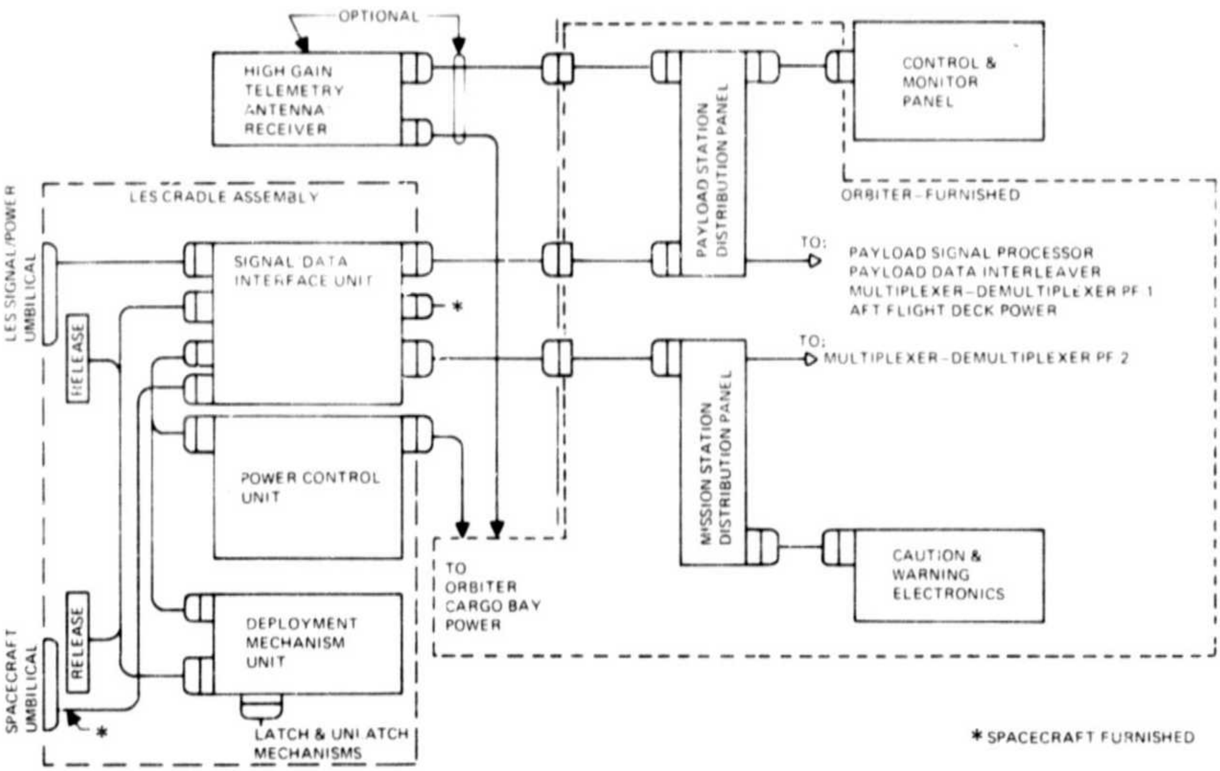

FIGURE 17 AVIONICS ASE INTERFACES

7.6 Ground Operations

A ground operations flow for a low energy stage at the field site, shown in Figure 18, represents the major activities performed from completion of receiving, uncrating and inspection of the preserviced fuel tanks and ordnance devices to preparation and the installation in the Orbiter cargo bay. This flow was used to derive timeline allocations for each task and to define support requirements such as personnel, equipment and facilities for cost estimating in later tasks. Each of these tasks, along with consistent timelines, were evaluated for manpower and skill loading at field site. A field team equipped with proper personnel/skills was estimated to be 18 men.

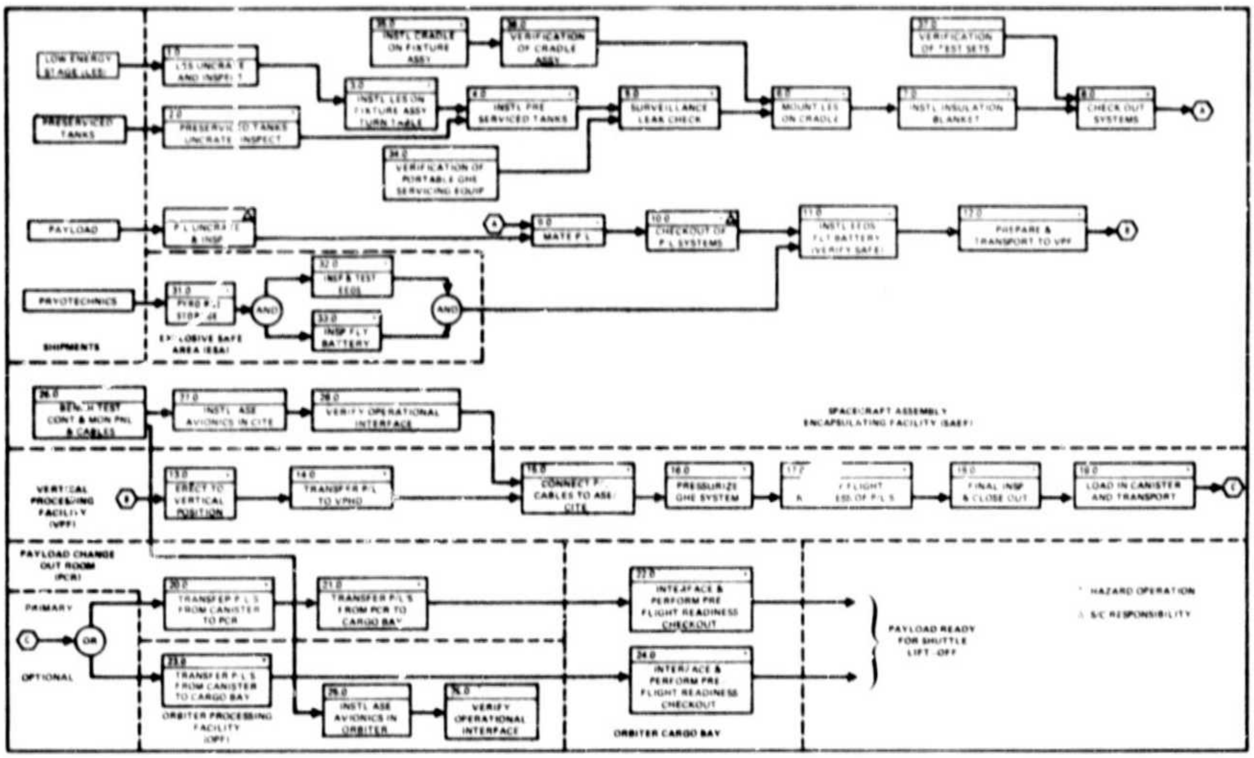

FIGURE 18 GROUND OPERATIONS FLOW DIAGRAM

7.6.1 Ground Support Equipment

Analysis of ground operations flow and the resulting processing timelines was performed to identify support equipment requirements when installation occurs at the Orbiter processing facility or at the pad. The equipment is listed in Table 8. A mobile flat bed assembly concept, illustrated in Figure 19, was developed for (1) assembly of the ASE cradle, low energy stage and payload, (2) checkout of these elements of the Shuttle payload, and (3) transport to either the Vertical Processing Facility or the Orbiter Processing Facility.

TABLE 8 GROUND SUPPORT EQUIPMENT

ITEM	DESCRIPTION	REQUIREMENT FACTORY	REQUIREMENT FIELD
	CHECKOUT		
1	Guidance and Control Test Set	X	X
2	TDY-43 Computer Test Set	X	X
3	Telemetry Test Set	X	X
4	Test Battery Simulator	X	X
5	Pyrotechnic Test Load Simulator	X	X
6	Thruster Test Load Simulator	X	X
7	Portable GHe Servicing Cart (with accessories)	X	X
8	Audio GHe Spectrometer	X	X
9	ASE/Avionics Simulator	X	X
10	Umbilical Simulator	X	X
11	Cables and Cable Plant	X	X
12	Electrical/Electronic Test Equipment	X	X
13	Control and Monitor Panel		X
14	Electro Explosive Devices Test Equipment (GFE)		X
	HANDLING TRANSPORTING AND ASSEMBLY		
15	Shipping Containers	X	X
16	Mobile Flat Bed Assembly		X
17	Hoist Sling for Tanks	X	X
18	Turn Over Hoist Sling for LES	X	X
19	Hoist Sling for Vertical Life of Payload at VPF		X
20	Fork Lift (GFE)		X
21	Truck (GFE)		X
22	Cradle Assembly		X
23	Multi-Mission Support Equipment (GFE)		X
24	Hoist Sling for LES	X	X
25	LES Handling/Assembly Dolly	X	
26	Hydroset	X	X
	MISCELLANEOUS		
27	Hand Tools	X	X
28	Safety Equipment	X	X

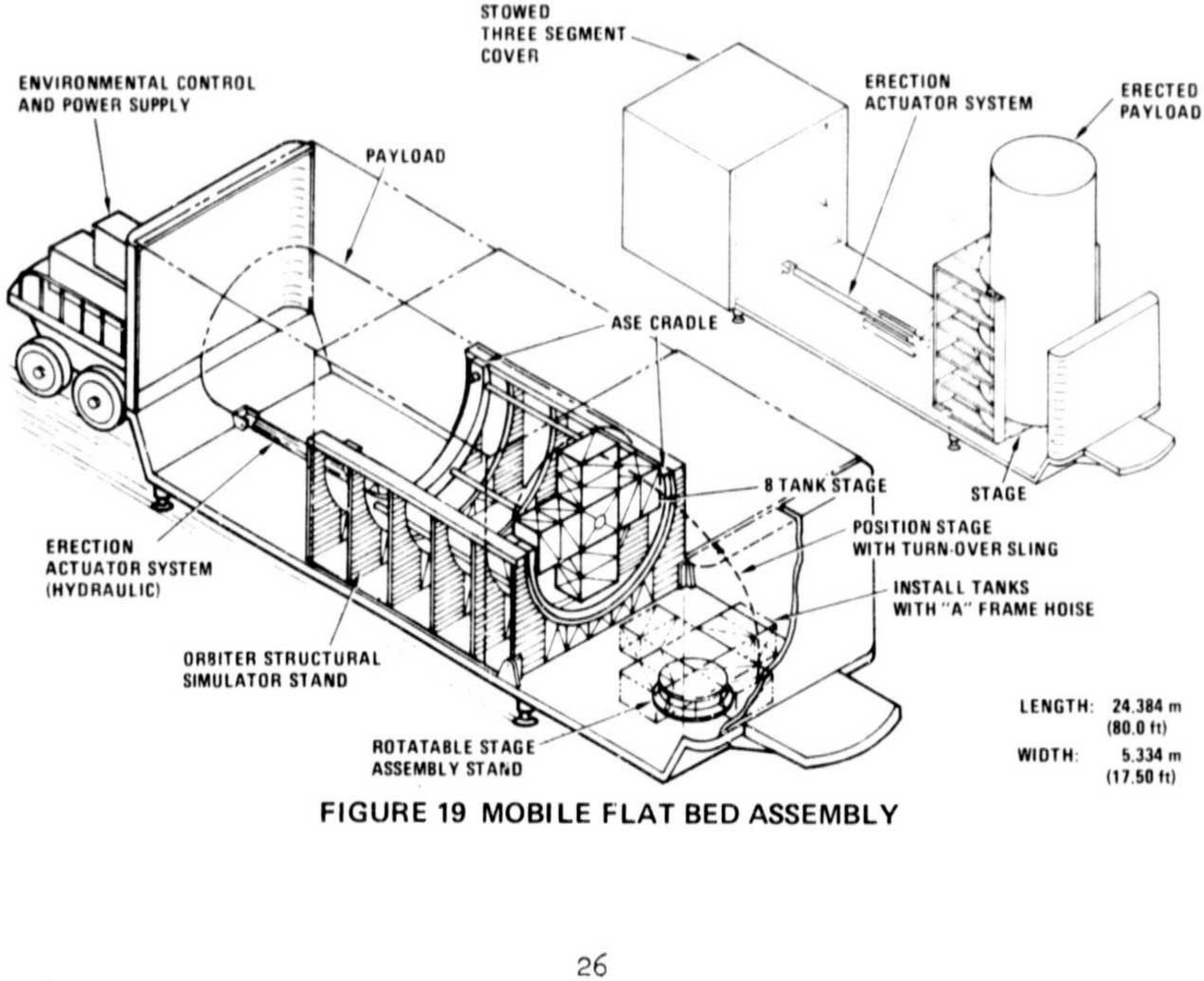

FIGURE 19 MOBILE FLAT BED ASSEMBLY

8.0 FINAL SCREENING AND SELECTION

8.1 Approach

The final screening and selection of the most cost-effective system to accommodate the low energy payloads was accomplished by a comprehensive cost analysis. The candidate approaches used in this analysis were derived from previous sections and are summarized in Table 9.

Since no single approach appears capable of economically handling all payloads of the mission model, the methodology used was to compare total life cycle costs of various combinations of approaches, or scenarios. Each approach in a given combination was chosen such that it would handle a logical group of payloads within the mission model most economically. This procedure is similar to that used in Section 6.0 in the initial screening of new propulsion systems. Life cycle costs include development, unit production, ASE, Shuttle users charge for both delivery mode and payload, and special costs (such as retrieval and refurbishment costs for the TRS reusable stage).

The overall procedural steps in the final screening and selection consist of (1) defining existing/planned systems costs, (2) deriving new propulsion system costs, (3) establishing logical scenario groupings and resultant costs, and (4) comparison of scenario costs and selection of lowest cost systems.

8.2 Existing/Planned Approaches

The costs for existing/planned systems are given in Table 10. This information was obtained from NASA manuals and documents, and from cognizant NASA sources for special cases. All costs used were verified by the Contracting Officer Representative.

8.3 New Propulsion Approaches

8.3.1 Costing Methodology

In Section 6.0 the new propulsion approaches were narrowed down to modular bipropellant and monopropellant liquid stages. Conceptual designs of these stages and adaptation to existing solids were carried out in Section 7.0. This task also defined ASE, GSE, and operations requirements. With this background information the costs of the two new systems were derived

TABLE 9 CANDIDATE APPROACHES SUMMARY

TYPE APPROACH	APPROACH	SOURCE
EXISTING/PLANNED	• INTEGRAL OMS (BASIC ORBITER WITHOUT OMS KITS) • BASIC ORBITER WITH OMS KITS • PM II (MMS) • TRS • SSUS-D; SSUS-A • SCOUT	SECTION 5.1
NEW STAGES	• LIQUID MONOPROPELLANT • LIQUID BIPROPELLANT	SECTION 6.0

TABLE 10 BASIC COSTING DATA – EXISTING/PLANNED SYSTEMS

APPROACH	LENGTH m	WEIGHT Kg	USE COST PER FLIGHT $M	UNIT COST $M	REMARKS
OMS Kits 1 2 3	 2.745 2.745 2.745	 7401 13379 19537	 .6 1.6 2.6	 - - -	Includes use and serial impact costs.
TRS (Reusable) 2 Tank 4 Tank	 2.13 2.13	 2718 4329	 .54 .6	 - -	Includes retrieval and refurbish cost. See Note 1 for additional program maintenance costs
PM-II (Expendable)	1.52	613	--	.98	See Note 1 for additional program maintenance costs.
SSUS-D SSUS-A	2.2* 2.6	1754 3770	1.2 1.2	2.43 3.64	Use cost includes mission analysis and launch services.
SCOUT WTR San Marco	 - -	 - -	 3.82 4.82	Included In Use Cost	Annual Program Maintenance Cost = $4.81M Additional cost for fifth stage = $.5M
Basic Shuttle User Charge	LENGTH OR WEIGHT LOAD FACTOR / .75 x $21.83M				Additional charge for non-standard altitude or inclination = $.2M

NOTE (1): Program Maintenance Costs - Annual Sustaining = $1.08M
Annual Field Operations = $ .62M for each launch site
Unit Field Operations = $ .31M for each stage launched

*Vertical installed bay length

and comparisons made.

Hardware component and subsystems quotes obtained from vendors constituted about 80% of new stage unit costs. The RCA PRICE costing system with its extensive data files of equipment and development costs was used to estimate and organize the costing of systems. These costs were then reviewed by Vought Engineering, Manufacturing, and Costing Representatives and in some cases adjustments were made to the mechanized cost evaluation techniques. A WBS structure was utilized to accumulate costs in order to maintain consistency. DDT&E costs of the modular new low energy stage systems concepts reflect commonality of subsystems and components. Development and acquisition of three sets of ASE and GSE (ETR, WTR, and spare) was included in DDT&E costs. Operations costs included costs to maintain operations at the contractors facilities and in the field and included both unit operation and annual costs. Shuttle charges escalated to 1977 dollars were consistent with those in the STS Users Handbook and Reimbursement Guide with two exceptions: a WTR standard Shuttle inclination of 98° was used instead of 104°, and a Shuttle charge for a non-standard orbit of $0.2M was included.

8.3.2 New Propulsion Approach Selection

Costs derived for the modular bipropellant and monopropellant stages as outlined above are summarized in Table 11. The total costs are essentially the same for the bipropellant and monopropellant systems. Cost to develop and produce the monopropellant system is less primarily because of the dual use of the four thrusters for main propulsion and reaction control. However, the greater length and heavier weight of this system (due to lower specific impulse) results in a higher Shuttle user charge. The two systems were considered essentially equal from the standpoint of total cost, development risk, accuracy, and Shuttle operations. The bipropellant system has a larger low energy regime payload capture, uses the cargo bay more efficiently, and has a greater potential for growth. For these reasons the bipropellant stage was selected for evaluation with existing/planned propulsion approaches in the remainder of the study.

TABLE 11 COSTING DATA – NEW PROPULSION APPROACHES (1977 – $M)

	MODULAR BIPROPELLANT	MODULAR MONOPROPELLANT
NON-RECURRING		
Basic Stage	$20.70M	$17.50M
ASE Dev & Prod. 3 Sets	$ 5.40M	$ 5.40M
Total DDT&E	$26.10M	$22.90M
RECURRING		
Unit Production	$2.13M - 8 Tank $1.76M - 4 Tank	$2.00M - 8 Tank $1.33M - 2 Tank
SHUTTLE USER CHARGE DATA		
Length	.77 m Horizontal 1.70 m Vertical	.88 m Horizontal 1.70 m Vertical
Weight	2351 kg - 8 Tank *1262 kg - 4 Tank	3506 kg - 8 Tank 1009 kg - 2 Tank
PROGRAM MAINTENANCE		
Annual Sustaining Operations	$1.08M	Same
Each Launch	$ .31M	Same
Annual ETR	$ .62M	Same
Annual WTR	$ .62M	Same

*A 50% off-load bipropellant has performance equivalent to the two tank monopropellant and weighs 847 kg.

8.4 Final Selection

In this section comparisons are conducted of combinations of existing/planned and new propulsion approaches and a final selection made. Each combination groups various propulsion approaches into logical operational arrangements in order to determine the most economical method of accommodating the low energy payload missions. There are a large number of possible combinations but experience gained in making cost comparisons during the study permitted choosing likely low cost combinations without resorting to extensive matrices of combinations. The costs used for comparisons were total program costs over the 12 year period 1985-1991 to launch all 129 payloads of the mission model. Costs included development where applicable, production, operations, and Shuttle user charges for both stage and payload.

8.4.1 Special Low and High Velocity Requirements

It was apparent early in the study that those payloads in the upper left corner of the low energy regime, Figure 2, are mostly telescopes and other large spacecraft that will probably require dedicated launches. These

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payloads can be delivered to their desired orbits directly by the Orbiter with integral OMS. Consequently, this forms the lowest cost approach for this class of payloads since the use of a stage to achieve the desired destination orbits from a standard Shuttle 296 km orbit would be more costly than the nominal $0.2M charge for a non-standard orbit. As a result, the Orbiter "Integral OMS" was used as a basic element of all combinations for those large payloads in this category.

The high energy requirements of the Scout class payloads were also examined. The options for launching these payloads are compared in Table 12. The second mode would require elliptical Shuttle orbits which may not be realistic for the shared flight costs shown. With the mission model launch rate the Scout ELV is the lowest cost approach for the higher energy payloads. After WTR is operational those Scout payloads requiring polar type orbits can be more economically accomplished from the Shuttle. In view of the above, the Scout launch vehicle was chosen as the basic element for all combinations for the Scout class payloads until WTR is operational in 1983.

TABLE 12 - SCOUT CLASS PAYLOAD LAUNCH COMPARISON

LAUNCH MODE	DESCRIPTION	AVERAGE UNIT LAUNCH COST FOR 10 SCOUT PAYLOADS 1980-1982 - $M
SCOUT	• Direct launch from ground as expendable launch vehicle	5.56
ORBITER/SSUS-D, A	• Orbiter provides payload perigee • SSUS stage provides circularization or elliptical orbit and plane change if required	7.70

8.4.2 Existing/Planned Systems

The first combinations were assembled around the existing/planned propulsion approaches starting with the basic Orbiter with its integral OMS tanks and Scout as discussed above, and then adding OMS kits and SSUS-D stage to supply added energy where required. The cost of this combination, E-3, is plotted in bar chart format in Figure 20 and shows a total program cost of $2.29B. The addition of PMII forms Combination E-5 and reduces the

costs to $1.75B. Employment of TRS in place of the OMS kits in E-5 constitutes Combination E-1 with a total program cost of $1.60B and is the lowest cost using existing/planned systems.

8.4.3 New and Existing/Planned Systems

The substitution of the 4-tank bipropellant stages for TRS and PMII in E-1, along with a SSUS-D adaptation, defines Combination C-3 with a total program cost of $1.55B. Substitution of the 8-tank bipropellant for the SSUS-D adaptation in Combination C-3 defines Combination C-2 with a total program cost of $1.48B. This is the lowest cost overall combination and also requires the fewest and simplest systems which are the basic Orbiter with integral OMS, a new modular bipropellant liquid system, and the current Scout launch vehicle.

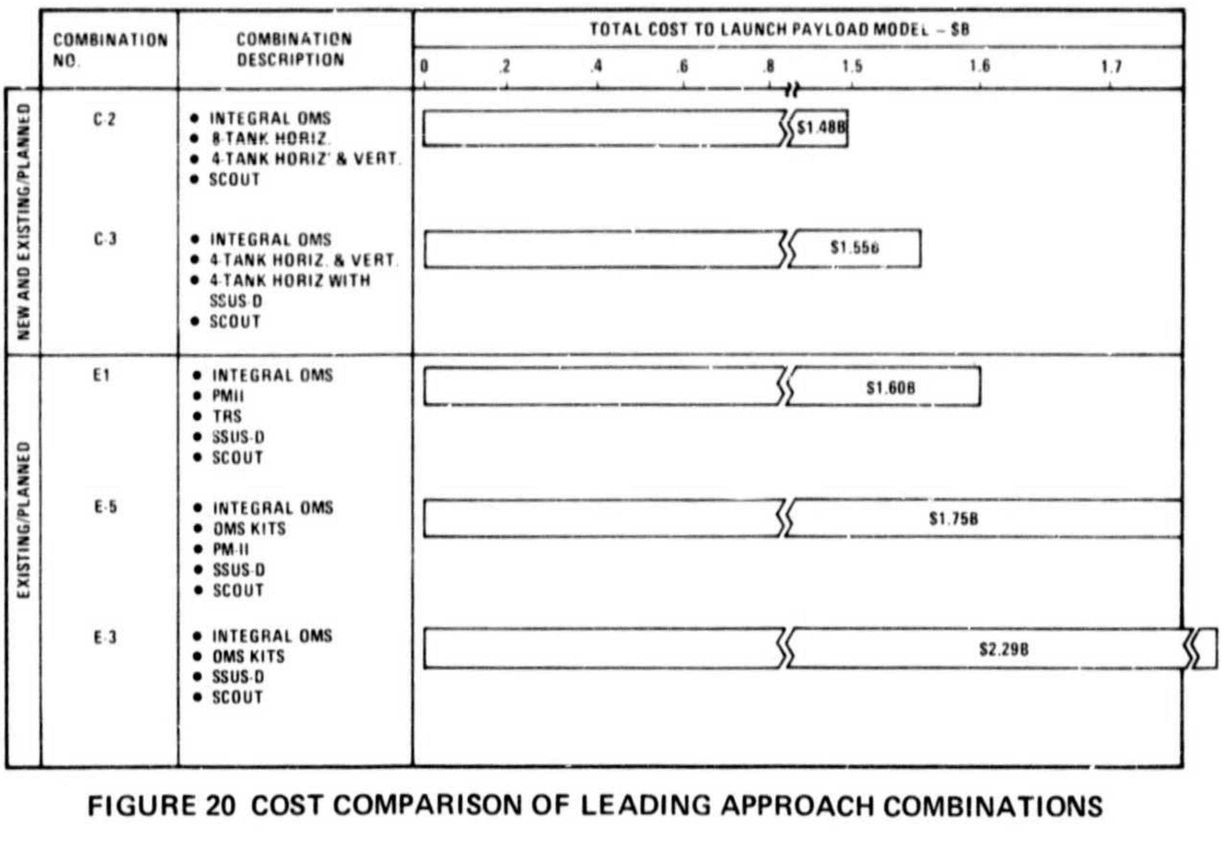


FIGURE 20 COST COMPARISON OF LEADING APPROACH COMBINATIONS

8.4.4 Life Cycle Costs

The cumulative life cycle costs to deliver the low energy payloads were examined in order to determine the effect of timing, as well as the magnitude of costs, in assessing the economic merits of the most attractive combinations. The results are presented in Figure 21.

For simplicity in illustrating the differences in life cycle costs between various combinations of propulsion approaches, the Shuttle user charge for the payloads which are common to both combinations has been omitted. The upper portion of Figure 21 shows that the total program cost savings with Combination C-2 is $121M and that this system begins to be more cost effective early in 1983. If the DDT&E costs for TRS are added to the E-1 combination costs (as indicated by the dotted line) the cost benefit to C-2 combination would increase to $147M. Inclusion of the PMII DDT&E costs would further increase the C-2 combination cost benefits.

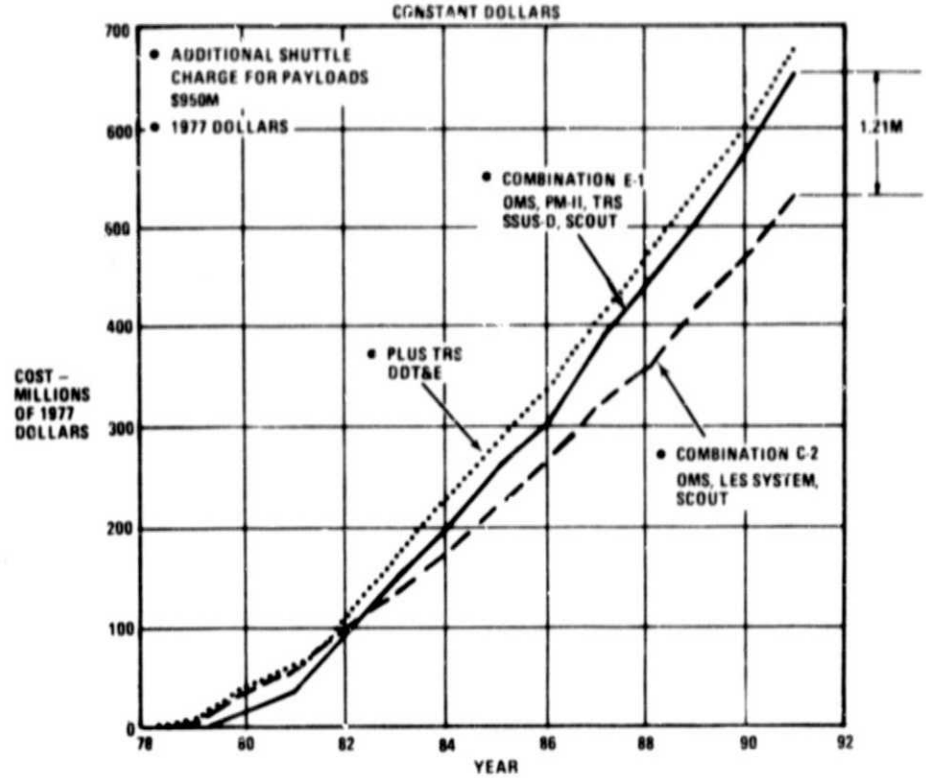
8.4.5 Selection

Within the groundrules of this study, the most economical approach for placing automated payloads into low energy earth orbits emerges as a combined system consisting of three elements:

- Existing Orbiter with integral OMS
- Existing Scout launch vehicle until Shuttle is operational from WTR
- A new modular bipropellant liquid stage

The distribution of payloads to each element of the system is summarized in Table 13.

The performance of this new modular liquid stage system is summarized in Figure 22. The performance capability of the 4 and 8 tank versions cover 85% of the low energy regime and encompass the requirements for all payloads after WTR is operational. If future payloads evolve with mission requirements beyond the capability of the 8 tank version, the adaptation of the 4 tank version to SSUS-D and SSUS-A can extend coverage over the entire low energy regime as indicated in the Figure.



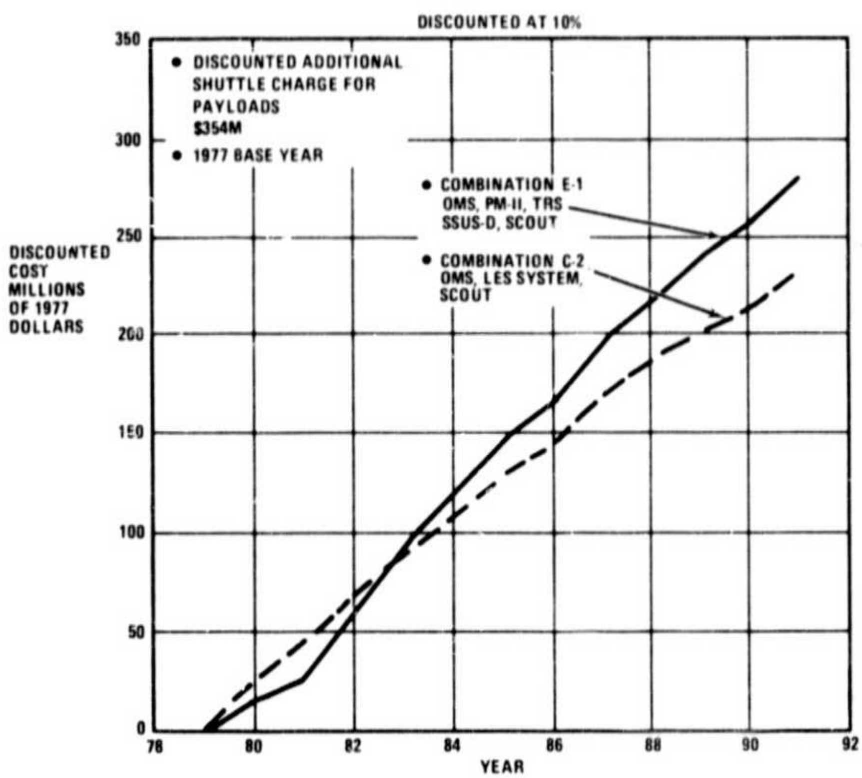


FIGURE 21 CUMULATIVE LIFE CYCLE COST

TABLE 13 PAYLOAD DISTRIBUTION OF SELECTED PROPULSION APPROACH

ELEMENT	NUMBER PAYLOADS
• Integral OMS	16
• Modular Bipropellant Liquid Stage	103
- 4 Tank Horizontal - 76	
- 4 Tank Vertical - 14	
- 8 Tank Horizontal - 13	
• Scout	10
TOTAL	129

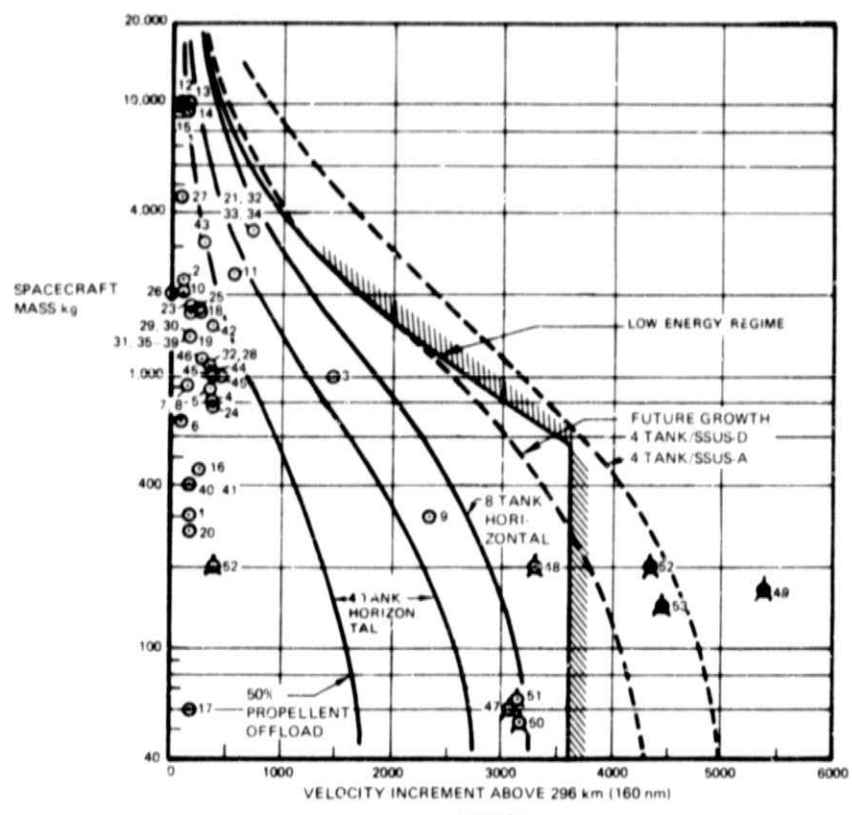


FIGURE 22 PERFORMANCE OF SELECTED NEW MODULAR LIQUID STAGE

9.0 IMPLEMENTATION

The nominal development program schedule for the selected modular liquid stage is 33 months from the authority to proceed to first launch. The major check points and funding schedule are shown in Figure 23. The 33 month schedule is consistent with nominal lead times for materials and testing. Figure 24 shows check points and funding for a 57 month program which features a lower funding rate without total program cost penalties.

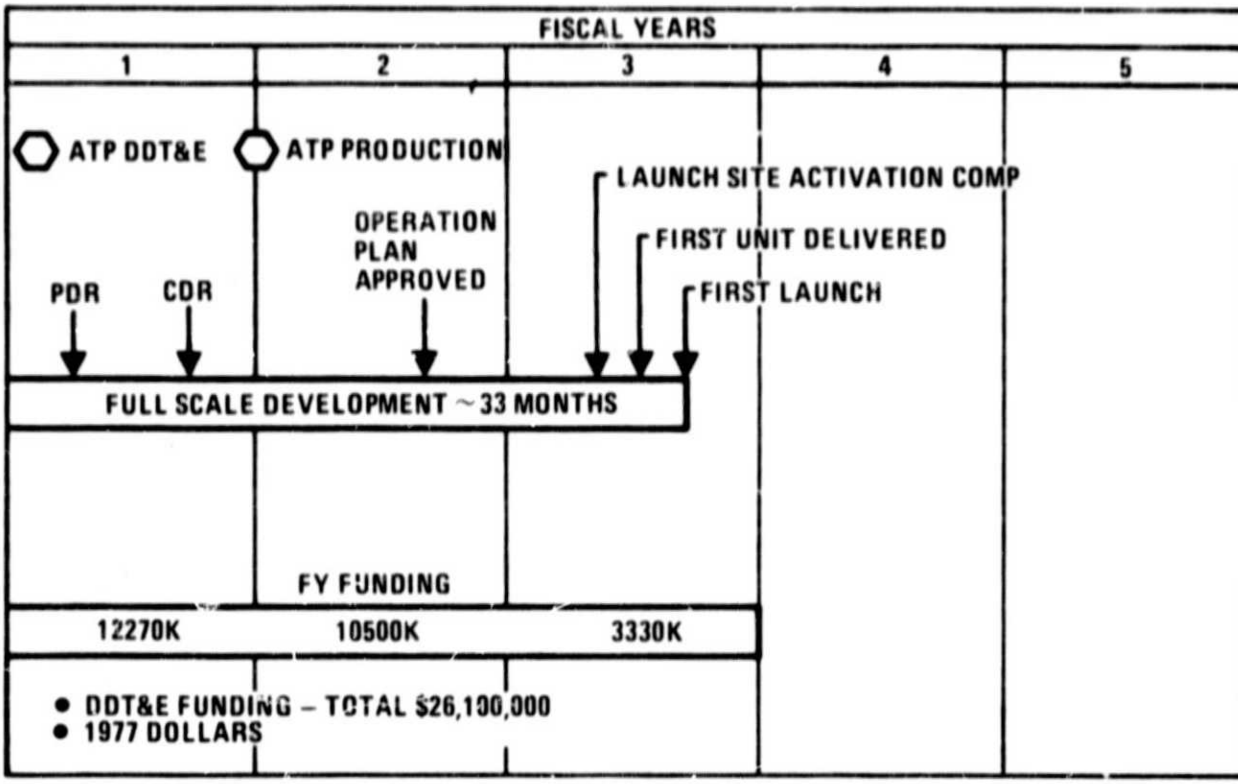


FIGURE 23 DEVELOPMENT AND FUNDING SCHEDULE

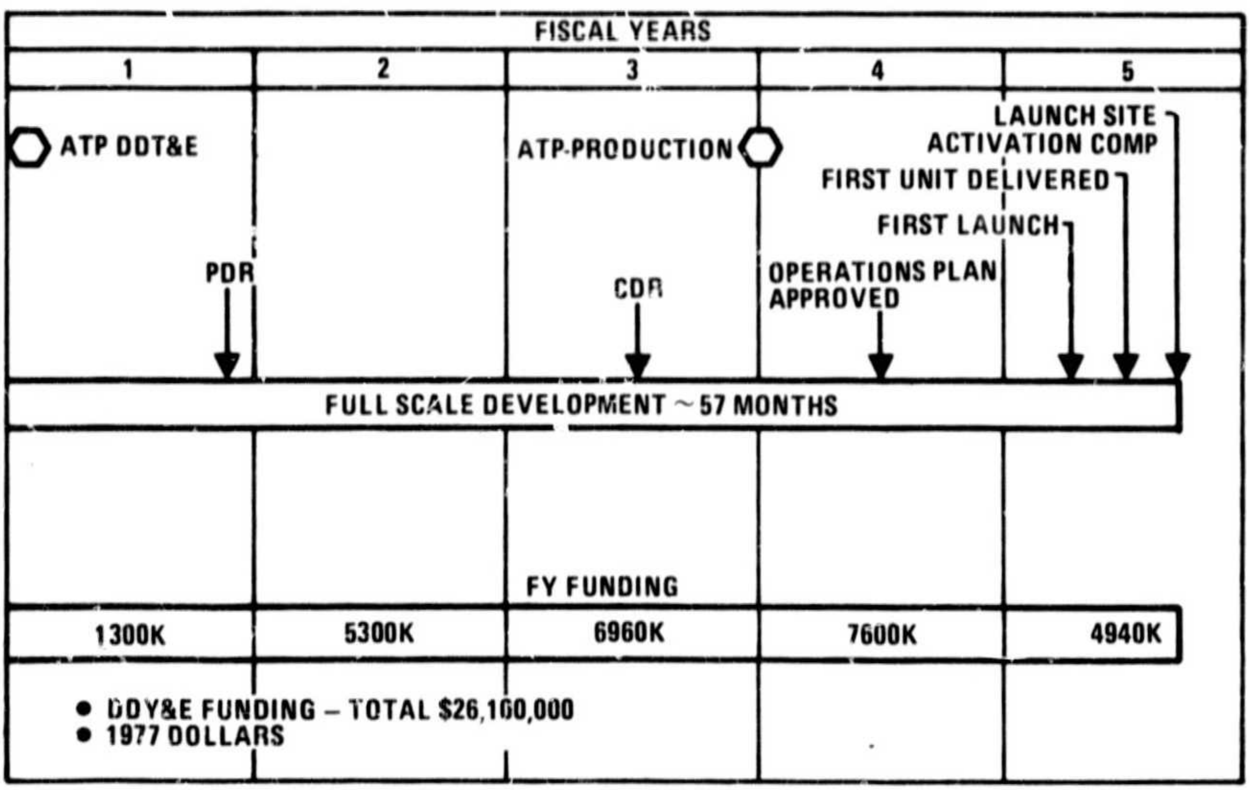


FIGURE 24 DEVELOPMENT AND FUNDING SCHEDULE

10.0 RECOMMENDATIONS

Within the groundrules of the study the recommended approach to launch the low energy regime payloads consists of the basic Orbiter, new modular liquid stage and Scout.

Based upon the analyses and evaluations performed in this study, and emerging Shuttle payload requirements, the following additional recommendations are made.

(1) Consideration should be given to the applicability, modifications required, and potential cost benefits of extending the modularity of the liquid propulsion system to produce the capability:

(a) To function as a spacecraft propulsion module for transfer of spacecraft to the destination orbit and to provide attitude and orbit control propulsion for the spacecraft throughout its life. The propulsion module to be integrated with the spacecraft guidance, power and communications. Both expendable and return to Shuttle for refurbishment and reuse of the propulsion module and spacecraft should be evaluated.

(b) To function as an independent upper stage to deliver a spacecraft to its destination orbit and later, to return the spacecraft to the Shuttle for refurbishment and reuse. In this application the system should be considered to provide transportation only or transportation and destination orbit support. The options to refurbish the spacecraft and stage and reuse from the Orbiter or from the earth should be considered.

(c) To function as a independent upper stage capable of spacecraft delivery or retrieval, return to the Orbiter after spacecraft delivery or retrieval for refurbishment, refueling and reuse from either the Shuttle orbit or from the earth.

(2) Consideration should be given to the development of a system of interface kits for physical and electronic mating of the propulsion module and stage with a broad spectrum of spacecraft to provide both integrated spacecraft propulsion module and independent stage support for the Space Transportation System.